REFLECTANCE COMPARISON BETWEEN SCIAMACHY AND A RADIATIVE TRANSFER CODE IN THE UV

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ABSTRACT

SCIAMACHY, onboard Envisat, is an Earth-monitoring spectrometer over the wavelength range 240–2400 nm. We compare its reflectance measurements in the UV with calculations by a polarised radiative transfer code for a cloud-free state over the Sahara desert. The SCIAMACHY reflectance between 240 and 400 nm is found to be too low by about 15–25%. The estimated error on this is less than 5%. The comparison method we present here can also be helpful for the in-flight calibration of other UV satellite spectrometers (like OMI, or GOME-2).

1. METHOD

We compared the reflectance measured by SCIAMACHY in the wavelength range 240–400 nm with the reflectance as calculated by a radiative transfer model (DAK). For this purpose, we selected a cloud-free Sahara state from verification orbit 2509 (August 23, 2002). An image of this state is shown in Fig. 1. The image was constructed by mixing the signals of three of SCIAMACHY's Polarisation Measurement Devices (PMDs) into RGB colours [1].

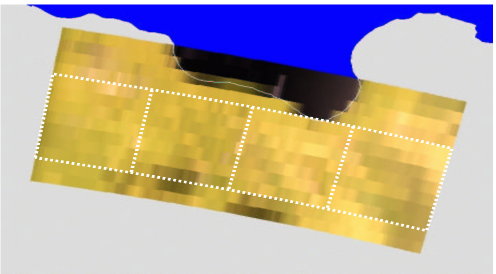

Fig. 1. Image of the selected Sahara desert state, created by converting the state signals of three of SCIAMACHY's PMDs (3, 4, and 2) into proper RGB colours.

For the chosen Sahara state, the surface albedo in the ultra-violet is relatively low, ~0.10, and well-known from GOME observations [2]. The ozone column at the time of SCIAMACHY's overpass is known with a fairly high precision from GOME data. On the other hand, the reflectance between 295 and 315 nm is very sensitive to the exact shape of the ozone profile. Therefore it is essential to use an actual estimate for the ozone profile instead of a climatological one. The ozone profile was retrieved from SCIAMACHY limb data [3] and the ozone column derived from the limb profile was checked against assimilated GOME data, and found to be 295 DU.

From the SCIAMACHY data of the state shown in Fig. 1 we constructed four sets of ground pixels, labeled 'east', 'center-east', 'center-west', and 'west'. For each of these sets we performed model calculations, based on their specific viewing and solar angles, surface pressure, surface albedo, ozone column and ozone profile. The ozone profile for each 'pixel set' is the limb profile scaled to the ozone column determined from interpolating assimilated GOME data to the correct time and location [4]. Using these input parameters the radiative transfer code DAK produced simulated spectra, which could then be compared with the SCIAMACHY measured reflectances.

2. RESULTS OF THE COMPARISON

As an example, Fig. 2 shows the reflectance as measured by SCIAMACHY, for channels 1 (purple) and 2 (blue), and the simulated (DAK) data (given in red). The data shown here originate from the 'east' pixel set that was constructed from the Sahara state data.

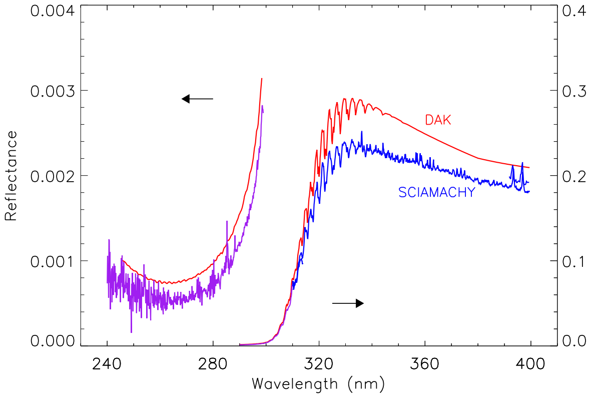

Fig. 2. Reflectance for spectral channel 1 (purple, use the left axis) and channel 2 (in blue, use the right axis). The simulated data are given in red. Clearly, SCIAMACHY underestimates the reflectance in both channels.

In Fig. 3 we present the relative difference between SCIAMACHY measurements and DAK calculations, calculated as (SCIAMACHY–DAK)/DAK, for all four SCIAMACHY viewing directions. The difference amounts to roughly –10% at 390 nm to about –30% at 250 nm. As can be seen from Fig. 3, there is only a very small

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spread between the results for different viewing directions, which may be related to uncertainties in the ozone and albedo values used for the simulation. The small spread in itself could be interpreted as an indication of a high accuracy within the whole procedure. Apart from that, the result immediately dismisses any ideas about scan angle dependent calibration problems, at least within the accuracy of the comparison. In the next section the accuracy of the method used will be investigated thoroughly and an error estimate will be presented as well.

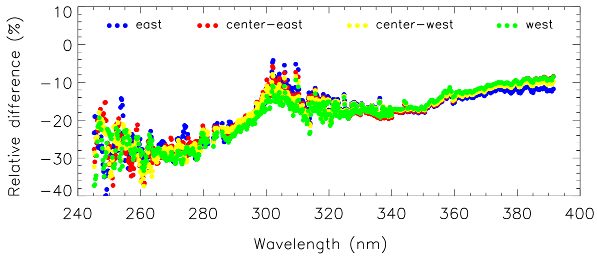

Fig. 3. Relative difference between the reflectance measured by SCIAMACHY and that of the simulated DAK data, for the Sahara state. Different colours are used to distinguish between the four different viewing directions.

3. SENSITIVITY TO INPUT PARAMETERS

We studied the sensitivity of the simulated reflectance, and hence of the comparison with SCIAMACHY, for the following DAK input parameters: ozone column, ozone profile, and surface albedo. Accurate knowledge of these sensitivities is important to help assess the origins of systematic deviations found between observation and simulation. An example is the "bump" seen in Fig. 3 near 305 nm: inspection of the derivative of reflectance w.r.t. ozone column reveals that a discrepancy in this area is most likely caused by inaccurate input (cf. Fig. 5).

3.1 Surface albedo sensitivity

In Fig. 4 we present the albedo sensitivity, defined here as $dR_\star/dA_\star = (dR/R)/(dA/A)$, as a function of wavelength, for the 'east' pixel, and for various surface types. The derivatives were calculated from different runs made by the DAK radiative transfer code, by introduction of a small relative change dA/A in the albedo A, and noting the effect dR upon the reflectance R. This was done for a variety of typical surface types, including 'snow', 'water', 'vegetation', 'soil', 'sand', and 'desert'. The latter surface albedo ('desert') was based entirely on the GOME LER database [2] and therefore refers specifically to the Saharan east pixel data set indicated in Fig. 1.

Looking at Fig. 4, it is obvious that below a wavelength of, say, 300 nm, a possible error in the surface albedo provided to the radiative transfer code does not influence the outcome of the comparison outlined in Sect. 1. Hence, accurate knowledge of the exact surface albedo is irrelevant for the shorter wavelengths. Above 300 nm, however, the sensitivity is slowly rising with wavelength, the albedo (error) having more and more impact on the reflectance (error). The exception to this, of course, is the 'snow' surface type, which jumps up immediately to a value of 1.0, which is the asymptotic value reached by all the surface types at higher wavelengths. Also notice the similarity between 'sand' and 'desert' surface types.

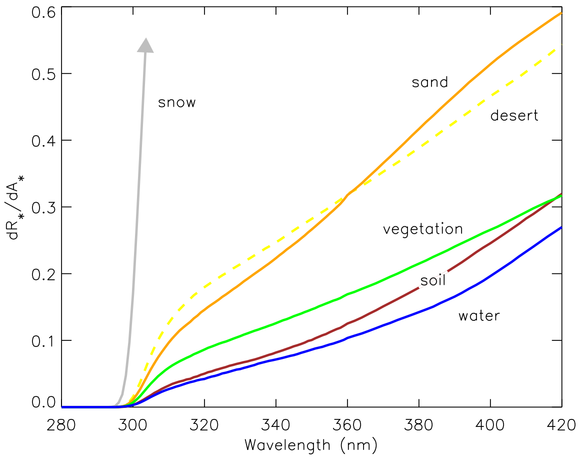

Fig. 4. Sensitivity of the reflectance on surface albedo in the UV as a function of wavelength for a number of surface types. The label 'desert' refers to the surface albedo used for the Sahara site discussed in Sect. 1.

Coming back to the comparison of SCIAMACHY and DAK, it appears that a reasonable error in the surface albedo value like 5% still allows a fair comparison up to around 400 nm (for the Sahara desert site under consideration). At still higher wavelengths, every percent error in the surface albedo translates roughly into a percent error in the comparison, which is rather unacceptable. It was checked that for other geometries (other viewing angles) the plots are completely comparable to that of Fig. 4.

3.2 Ozone column sensitivity

Fig. 5 shows the sensitivity of the reflectance on ozone column, $dR_\star/dO_{3\star} = (dR/R)/(dO_3/O_3)$, as a function of wavelength for three ozone values. The data again refer to the Saharan 'east' pixel data set, which had an ozone column of 295 DU, as mentioned before. The plot shows that above 330 nm the sensitivity to the ozone column is very small, and for these wavelengths inserting a proper value for the ozone column is not all that important. Below 330 nm, the ozone column used has a much larger impact on the model reflectance, in particular in the region around 305 nm, where multiple Rayleigh scattering is the dominant mechanism for radiative transfer.

When the sensitivity is re-calculated for different ozone columns, the resulting sensitivity curve is altered in

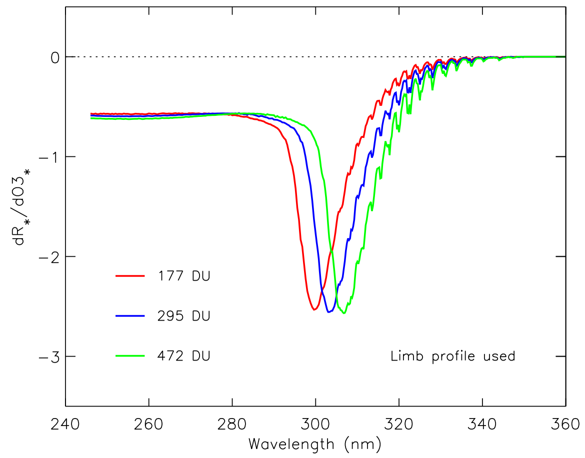

Fig. 5. Sensitivity of the reflectance on ozone column value for three typical ozone columns. Notice the sharp peak around 305 nm, caused by the onset of multiple Rayleigh scattering. The position of the peak changes with the ozone value used; the shape remains the same.

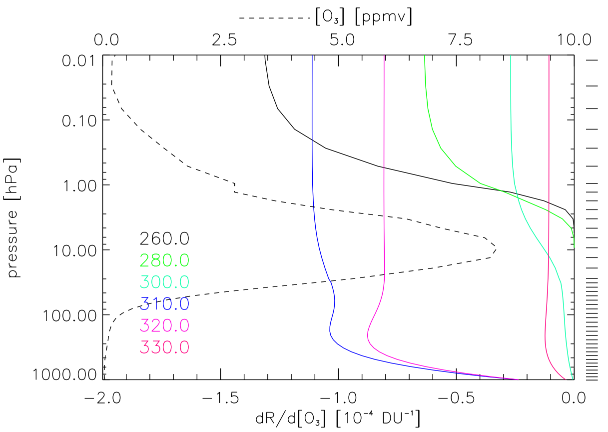

Fig. 6. Coloured lines: derivatives of the reflectance in the 'east' pixel w.r.t. the ozone profile, for six wavelengths, in units of $10^{-4}\mathrm{DU}^{-1}$ per model layer. Dashed curve: ozone profile as retrieved from SCIAMACHY limb observations, in ppmv. On the right, the model pressure grid that was used in the calculations is shown.

that it changes its position in the spectrum. More specifically, it moves to the right when the calculations are done for higher ozone columns. The relevance of Fig. 5 for the model calculations presented in Sect. 2 of this paper is that it explains the "bump" seen in Fig. 3 to be caused by a (small) error in the ozone value that was used for the simulations. At the same time, Fig. 5 tells us that the resulting height of the bump, which is about 10% in Fig. 3, can therefore be minimised by changing the ozone column by ∼4%. The bump in other words reveals small discrepancies in the ozone column values used, and can therefore be used to fine-tune the ozone column input parameter for the model calculations. This way, the accuracy of model comparisons such as presented in Sect. 2 can be improved greatly. It was again verified that other geometries (i.e. other sets of solar and viewing angles) result in plots quite similar to that shown in Fig. 5.

3.3 Ozone profile sensitivity

To understand the previous result, and to study the influence of the atmospheric ozone *profile*, rather than its *column* we used another radiative transfer model, called LIDORT. With LIDORT, the derivatives of the reflectance w.r.t. the ozone profile can be calculated. Since LIDORT uses analytical expressions for these derivatives, these can be calculated at marginal extra computational cost.

In Fig. 6 we present the sensitivity of the reflectance spectra to the ozone profile at a height z, $dR/dO_3[z]$, for six wavelengths in the UV, along with the ozone profile itself (dotted curve) and an indication of the model pressure levels. The ozone profile, as mentioned in the Introduction, is not a climatological one, but it is the one obtained from SCIAMACHY limb data [3]. As before, the result in principle only holds for the constructed 'east' pixel set, but it was checked that the results presented here are in fact quite general for unclouded scenes.

The result clearly separates the different regimes. For 260 and 280 nm, for instance, the derivative is non-zero only at high altitudes, where severe ozone absorption prevents light from reaching lower altitudes. At 300 and 310 nm, radiation may reach the lower atmosphere and the derivative is high for all heights. At 320 and 330 nm, the derivative is small everywhere as ozone absorption is low anyway and (Rayleigh) scattering takes place in the entire atmosphere, not only in the higher (ozone) levels.

3.4 Error analysis

We are now in a position to give an error estimate for the main result of this paper, Fig. 3. First of all, the "bump" near 305 nm was fully identified as a ∼4% error in the value used for the ozone column in the model calculations (cf. Sect. 3.2). According to Fig. 5, this translates into an error in the model reflectance of around 2% in the wavelength region up to 290 nm, and 0% above 330 nm.

As for the surface albedo, we estimate the values we used in the model calculations to be accurate within at least 10%. Consulting Fig. 4 leads us to believe that below 300 nm, the error in the modeled reflectance is negligible, and above 300 nm, the reflectance error will not exceed 5%. Looking back at Fig. 3, it appears that these numbers agree well with the maximum spread that is found in the reported errors for different viewing angles. In conclusion, the relative difference between SCIAMACHY and DAK as reported in Fig. 3 is accurate within 5% at least. Table 1, finally, summarizes the results.

Table 1. Relative difference between SCIAMACHY and model calculations of the reflectance for four typical wavelengths, taken from Fig. 3. The accuracy of these numbers and the necessary reflectance correction factors have been given as well.

	deviation	accuracy	correction
260 nm	–30 %	± 4%	1.43
300 nm	–22 %	± 5%	1.28
340 nm	–18 %	± 2%	1.22
390 nm	–10 %	± 3%	1.11

4. CONCLUSIONS

We found the current official SCIAMACHY Level-1c product (S.V. 5.01) to underestimate the Earth's reflectance between 240 and 400 nm by about 20% in magnitude, more or less depending on the wavelength, and accurate within at least 5%. We did not find a dependence on the viewing geometry. As for the here presented calibration problem of SCIAMACHY, comparisons like these should and will be extended to larger amounts of data, so that more reliable statistical analyses can be made. The type of comparison we present here may in fact be useful for the in-flight calibration of other UV satellite spectrometers like OMI, or GOME-2.

Acknowledgement

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5. REFERENCES

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