VERIFICATION OF SCIAMACHY'S POLARISATION CORRECTION OVER THE SAHARA DESERT

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ABSTRACT

The justification for doing the work presented in this paper lies in the recent and disturbing rumours regarding the reflectivity of the current SCIAMACHY Level 1b product. The reflectivity was claimed to show an overall 20-percent loss in magnitude compared to GOME. We will show that the reported discrepancy in the reflectivity is indeed not a fictional one, but that it is certainly not caused by the failing polarisation correction. We also concentrate on the polarisation correction itself. Unfortunately, the current version of the polarisation correction algorithm is not reliable, and shows severe errors in the applied correction.

1. POLARISATION CORRECTION OF RADIANCES

Light can be described by means of Stokes vectors $\{I,Q,U,V\}$, in which the component I refers to the intensity of the radiation, and Q and U characterize the degree of linear polarisation [1]. Circular polarisation, described by the Stokes parameter V, is negligible for atmospheric polarisation [2]. The spectral channels of SCIAMACHY are sensitive to the polarisation of the light it detects. This is an unwanted property. Because of the sensitivity of the spectral channels to polarisation, the response to detected atmospheric light $\{I,Q,U\}$ is unfortunately not just a linear function of the intensity I, but also depends on the Stokes parameters Q and U describing the (linear) polarisation of the radiation. More specifically, it is given by [3]

$$S_{\rm pol} = M_1\, I\, \{1+\mu_2^D Q/I + \mu_3^D U/I\} = S_{\rm unpol}/c_{\rm pol}\ , \tag{1}$$

which defines

$$c_{\rm pol} = \{1+\mu_2^D Q/I + \mu_3^D U/I\}^{-1}\ . \tag{2}$$

In Eq. 1 the term $S_{\rm pol}$ refers to the detector signal after exposure to polarised light. Alternatively, $S_{\rm unpol}$ is the signal caused by unpolarised radiation. As for the Mueller matrix elements μ_2^D and μ_3^D, these can be obtained from what has become known as 'the Greek Key Data set' [3]. Both elements are plotted in Fig. 1 as a function of wavelength, for the in this paper relevant wavelength range between 300 and 400 nm, and for the east and west viewing geometries of SCIAMACHY. It is important to realise that $S_{\rm pol}$ is the signal that is actually being reported by the detector pixel, while $S_{\rm unpol} \propto I$ is the signal we are interested in. When the normalised Stokes parameters Q/I and U/I are known, the 'unpolarised' signal $S_{\rm unpol}$ can be obtained applying Eq. 1.

2. COMPARING THE REFLECTIVITY WITH SIMULATIONS

In investigating the reflectivity, we concentrated on a particular state of the recently recalibrated orbit 2509 over the Sahara desert (Latitude +31°N, Longitude +18°E). It was thoroughly checked [4] that this state was completely free of clouds. Additionally, the surface albedo for Sahara surface is accurately known, especially in the UV [5]. This allowed for an accurate numerical approach, which we based on the radiative transfer code DAK ('Doubling-Adding KNMI'), which utilises a polarised doubling-adding method. We simulated the Sahara spectra for all four SCIAMACHY scanning geometries (notably the east, center-east, center-west, and west geometries). This was done for the wavelength region between 300 and 400 nm, and even beyond that up to around 800 nm. At these higher wavelengths, however, the surface albedo we used is considered to be less reliable.

The DAK code not only calculates the intensity I, but also the normalised Stokes parameters Q/I and U/I. In other words, all atmospheric relevant properties are known, which allows the important parameter $c_{\rm pol}$ of Eq. 2 to be determined. In order to directly compare SCIAMACHY reflectivity spectra with the simulated spectra, that is, without having to worry about the influence of a possibly wrong polarisation correction, we divided the DAK reflectivity by $c_{\rm pol}$ according to Eq. 1 and compared it to SCIAMACHY spectra which were not corrected for polarisation. The result of this exercise is shown in Fig. 2, which presents the reflectivity over the wavelength region ranging from 300 to 400 nm, which happens to be the spectral range of spectral channel 2. In the graph, the green curve belongs to the reflectivity $R_{\rm dak}$ calculated by DAK and the red curve denotes $R_{\rm dak}/c_{\rm pol}$. The blue curve, finally, is the reflectivity $R_{\rm pol}$ reported by SCIAMACHY after having switched off its polarisation correction. Obviously, a major discrepancy is present as we find $R_{\rm pol} \neq R_{\rm dak}/c_{\rm pol}$.

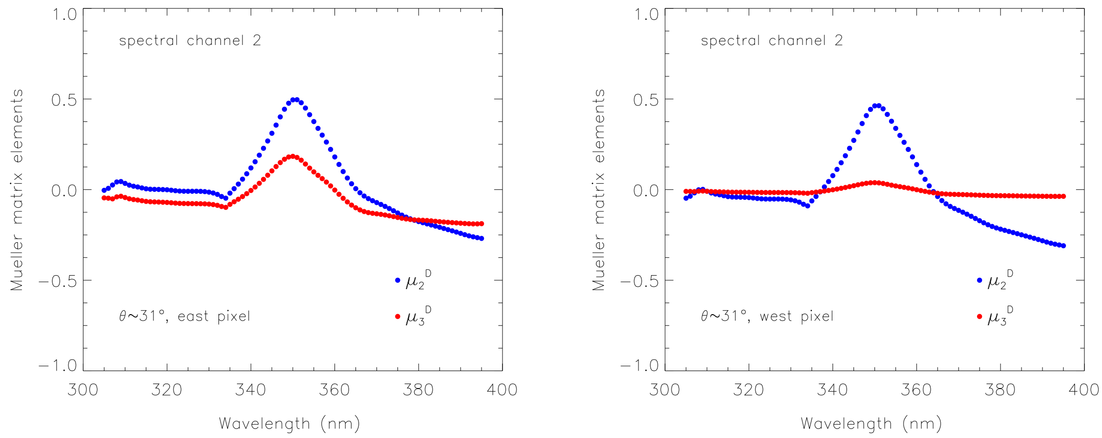

Fig. 1: Mueller matrix elements μ_2^D and μ_3^D as a function of wavelength for the east (left-hand side figure) and west (right-hand side figure) viewing geometries of SCIAMACHY. Notice that both elements are small, apart from the region around 350 nm. Here the need for a reliable polarisation correction is high, especially for the east case.

3. RESULTS OF COMPARISON

First of all, the blue curves in Fig. 2 do not even come close to the red curves, which indicates that the SCIAMACHY data underestimate the actual reflectivity. For convenience, we have attempted to illustrate this more clearly with Fig. 3. Here we have plotted the relative differences $(R_{\text{pol}} - R_{\text{dak}}/c_{\text{pol}})/R_{\text{dak}}$ (given by red circles) and $(R_{\text{pol}} - R_{\text{dak}})/R_{\text{dak}}$ (green diamonds). The conclusion is straightforward. For the west pixel, the difference is on the average about 20 percent, 4 percent larger than for the east case. These numbers are confirmed by the observations of Kerridge *et al.* [6] who stumbled onto a difference of about 21 percent in comparing SCIAMACHY data with GOME data, although it should be mentioned that there were some doubts about the validity of their approach. Nevertheless, the simulations we performed allow little room for uncertainty over the present wavelength range and we estimate these to be accurate within about 5 percent.

Secondly, in Fig. 2, the green and red curves denote the DAK results R_{dak} and $R_{\text{dak}}/c_{\text{pol}}$, respectively, and from these it is obvious (and also from Figs. 1 and 3) that below 340 nm the polarisation factor c_{pol} does not play a significant role. For the west pixel this is the case for the entire wavelength region, because here Q/I and U/I have become small as the viewing geometry in this case has approached the backscattering condition, for which we must have $Q = U = 0$ purely based on symmetry arguments alone. In other words, we can safely rule out that the 20-percent difference is due to a failing polarisation correction (which is *not* to say the polarisation correction is *not* failing, because it is). On the other hand, the 'bump' around 350 nm is definitely a polarisation feature, as was claimed by Kerridge *et al.* [6].

A third point that should be made is that the 20-percent difference is but an average over cluster 9 (which is part of spectral channel 2). Along the spectrum, the difference is somewhat varying. If we extend our analysis to the wavelength range $300-800$ nm, we notice that for the east pixel, the difference remains roughly fixed but for the west pixel it goes down and at some point even becomes negative (overestimate of the reflectivity). This behaviour could, however, be caused by the previously mentioned uncertainty in the Sahara albedo at these wavelengths. We therefore restrict ourselves to giving statements about spectral channel 2 only (Fig. 3).

4. POLARISATION CORRECTION AND ITS RELIABILITY

Fig. 4 is meant to illustrate the importance as well as the influence of polarisation on the detector signal. The red and green curves are basically representing the same DAK reflectivities as shown in Fig. 2, but now the wavelength range has been extended to 800 nm. For the west pixel, the effect is small if not absent, as motivated in the previous section. For the east pixel, however, the effect is quite high. For the wavelength region between 340 and 410 nm a proper polarisation correction is absolutely essential.

As for the current polarisation correction (SciaL1C 2.0.7; SCIA/4.00) itself, its performance and reliability can be found from Fig. 5. Here we have plotted R_{pol} and R_{unpol} of cluster 9, which, in line with the earlier definition, stand for the SCIAMACHY reflectivities obtained without and with polarisation correction, respectively. For the east pixel, the 'bump' in the reflectivity around 350 nm is almost removed, but not completely. This is most likely related to very small errors in Q/I and U/I. Indeed, the Stokes parameters have been showing large errors [7]. For the west pixel the situation is more serious. The Polarisation Correction Algorithm (PCA) makes the situation worse than it was. Unfortunately, there must be something seriously wrong with the PCA, or with its software implementation in the $0-1$ processor, because with the Q/I and U/I that were calculated by the PCA for PMD 1 (around 350 nm) we would end up with an improvement, rather

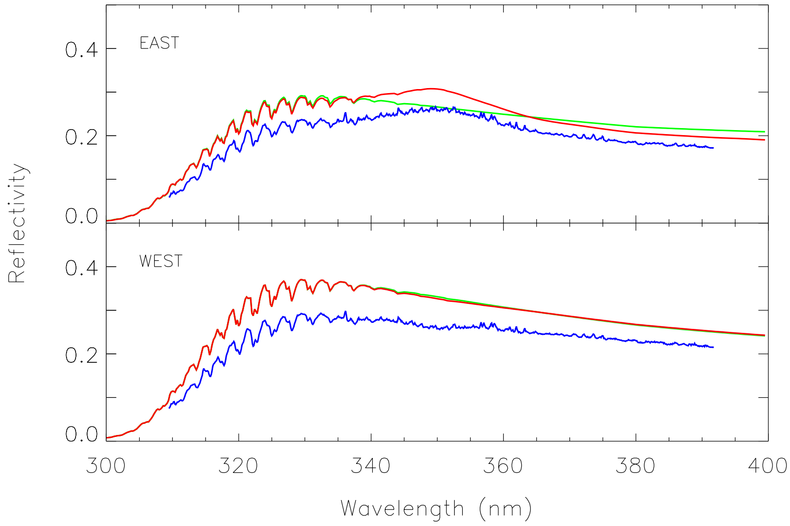

Fig. 2: Reflectivity as a function of wavelength. The green curve corresponds to the DAK simulated reflectivity for the selected Sahara site. The red coloured curve represents the same reflectivity, but divided by c_{pol}. Ideally, we would like it to equal the blue curve, which is the reflectivity SCIAMACHY recorded for spectral cluster 9 ("UV DOAS"), but obtained with the polarisation correction switched off. East and west pixels.

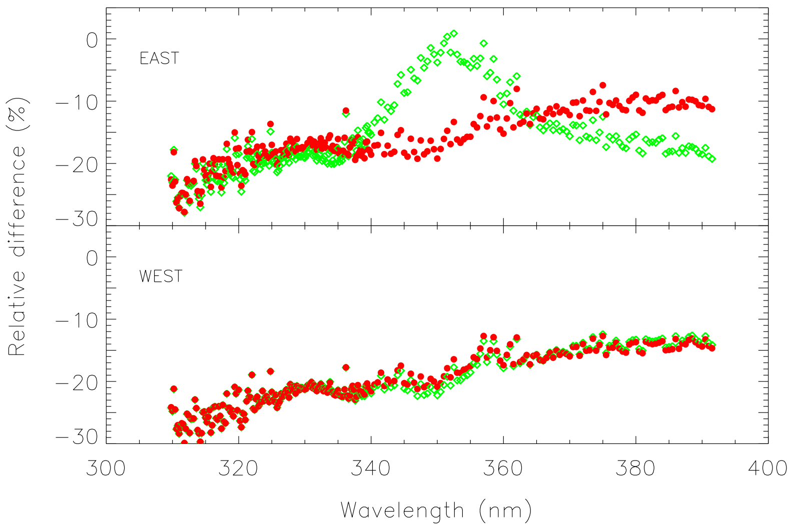

Fig. 3: Difference between the SCIAMACHY reflectivity and the simulated DAK reflectivity, relative to the DAK result. The colour usage is completely in line with Fig. 2, i.e. red equals $(R_{\text{pol}} - R_{\text{dak}}/c_{\text{pol}})/R_{\text{dak}}$ and the green diamonds refer to $(R_{\text{pol}} - R_{\text{dak}})/R_{\text{dak}}$. The result is given for the constructed east and west pixels of the Sahara state. Notice the small over-correction for the 'bump' around 350 nm in the east case.

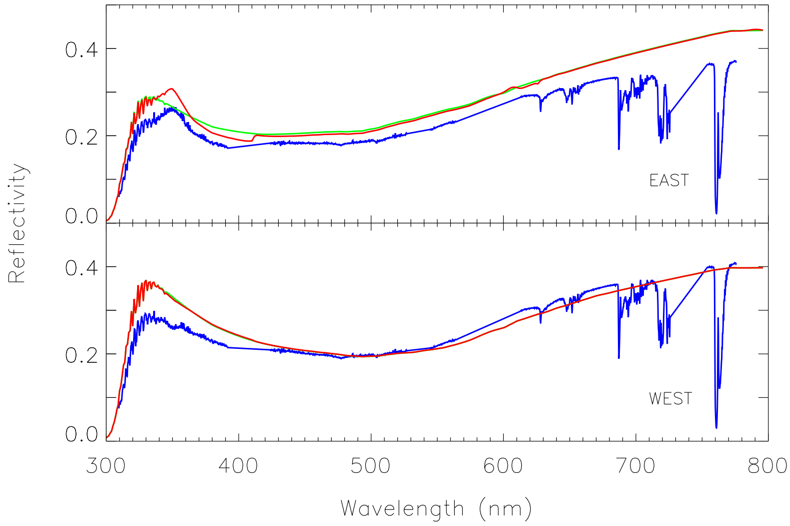

Fig. 4: Again we have set out the reflectivity against the wavelength, but now for the interval ranging from 300 to 800 nm. The green curve displays the simulated DAK results, the red curve presents the DAK reflectivity divided by c_{pol}, as before. East and west pixels. The graph illustrates the need for a proper polarisation correction in the near ultra-violet, as the necessary correction can be even much larger for other geometries.

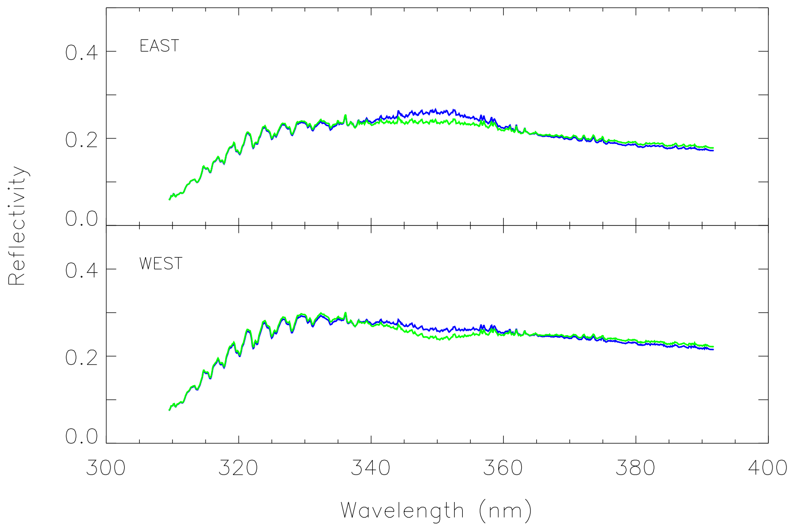

Fig. 5: Performance of the polarisation correction. The blue curve corresponds to the reflectivity without polarisation correction, the green coloured curve refers to the same reflectivity but now with the polarisation correction switched on. For the east pixel, the applied correction improves the reflectivity, but not completely. For the west pixel applying the correction dramatically worsens the result.

than a setback. It looks like the problem with the PCA is not restricted to just a wrongly calculated Stokes vector. In all cases, the PCA is not able to correct for the polarisation sensitivity of the detectors.

5. CONCLUSIONS

We have studied the radiometric calibration problem of the SCIAMACHY Level 1b reflectivity by using a radiative transfer code to emulate a particular, cloud-free state over the Sahara desert. It turns out that SCIAMACHY systematically underestimates Earth's reflectivity. More specifically, SCIAMACHY's reflectivity of a west scan is too low by some 20 percent and in the east scanning direction by about 16 percent. These numbers agree nicely with an earlier comparison between SCIAMACHY data and GOME data. More importantly, we showed that the polarisation correction, although in a bad shape, is not responsible for the discrepancy. Finally, we showed some serious problems in the present state (SciaL1C 2.0.7; SCIA/4.00) of the polarisation correction.

Acknowledgement

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6. REFERENCES

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