CURRENT STATUS OF SCIAMACHY POLARISATION MEASUREMENTS

J.M. Krijger[1] and L.G. Tilstra[2]

[1]SRON (National Institute for Space Research), Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands, krijger@sron.nl
[2]KNMI (Royal Netherlands Meteorological Institute), PO Box 201, 3730 AE De Bilt, The Netherlands, tilstra@knmi.nl

ABSTRACT

The measured signals by SCIAMACHY are corrected by a Polarisation Correction Algorithm to transform the signals to those that would have been measured for unpolarised light. This is achieved by transforming the signals of seven broadband Polarisation Measurement Devices onboard SCIAMACHY to the fractional Stokes parameters Q and U and interpolating them across the whole wavelength range of SCIAMACHY. At the moment of this report the fractional Stokes parameters Q and U as determined by the data-processor show unphysical values, except for the two Polarisation Measurement Devices at the shortest wavelength, as shown by a comparison with GOME polarisation measurements.

1. INTRODUCTION

The signals measured by SCIAMACHY are dependent on the Stokes parameters (I,Q,U, and V) [1] of the incoming light, while the radiometric calibration assumes an unpolarised input. Light reflected from the Earth and its atmosphere is often linearly polarised whereas the amount of circular polarisation (V) is negligible. To correct for this a Polarisation Correction Algorithm (PCA) is used to transform the measured main signal to the signal that would have been measured for unpolarised light (Q = U = V = 0).

This is done by determining the fractional Stokes Parameters Q/I and U/I (from now on simply Q and U) at specific wavelengths, either by theoretical (single scattering) models, broadband Polarisation Measurement Devices onboard SCIAMACHY (PMDs), and by main channel overlaps. The next step is to interpolate these determined Q and U values across the whole wavelength range of SCIAMACHY. The measured signal is then transformed to an 'unpolarised' main channel signal using the on-ground determined polarisation sensitivities of the main channels and the interpolated Q(λ) and U(λ). In this report we focus on the derived fractional Stokes parameters Q and U prior to the wavelength interpolation. As the interpolation and actual polarisation correction are derived from these measured values they cannot be correct if the PCA already fails at this point.

2. POLARISATION FRACTION FROM THEORY

Below 300 nm the polarisation is dominated by Rayleigh single scattering which only depends on the viewing geometry. This theoretical point is used for the first Q and U determination (from now on called $Q_{\mathrm{s.s.}}$ and $U_{\mathrm{s.s.}}$). An error in the sign of $U_{\mathrm{s.s.}}$ was found by L.G.Tilstra et al. [2], which has now been corrected for in the PCA.

3. POLARISATION FRACTION FROM PMDS

Onboard SCIAMACHY are 7 PMDs that have different polarisation sensitivity compared to the main science channels. They are mostly sensitive to the Q Stokes parameter, yet are also influenced by U. The seventh PMD however is more sensitive to U and is often called PMD_{45}. This difference in sensitivity allows the determination of Q (and/or U). In this report we refer to the PMDs as 1,2,3,…7, instead of A, B, C,…G as in [3].

The PMDs measure the intensity in one specific polarisation direction (overlapping mostly in wavelength with the main channels). By comparing the PMD signals measured in the main channels the fractional polarisation values can be determined. However the PMDs are much broader in spectral bandwidth than the main channels. As such a measured PMD signal can be written as the sum of measured main channel signals over all pixels that overlap in wavelength:

$$S_{\mathrm{PMD}} = \sum_{i=i_{start}}^{i_{end}} S_i \frac{M_{i,1}^P}{M_{i,1}^D} \frac{(1+\mu 2_i^P Q + \mu 3_i^P U)}{(1+\mu 2_i^D Q + \mu 3_i^D U)} \tag{1}$$

with index i the main channel pixel number from the start of the PMD overlap to the end of the PMD overlap, $M_{i,1}^P/M_{i,1}^D$ describing the ratio (of the PMD in question compared to the main channel) in radiance response to unpolarised light,

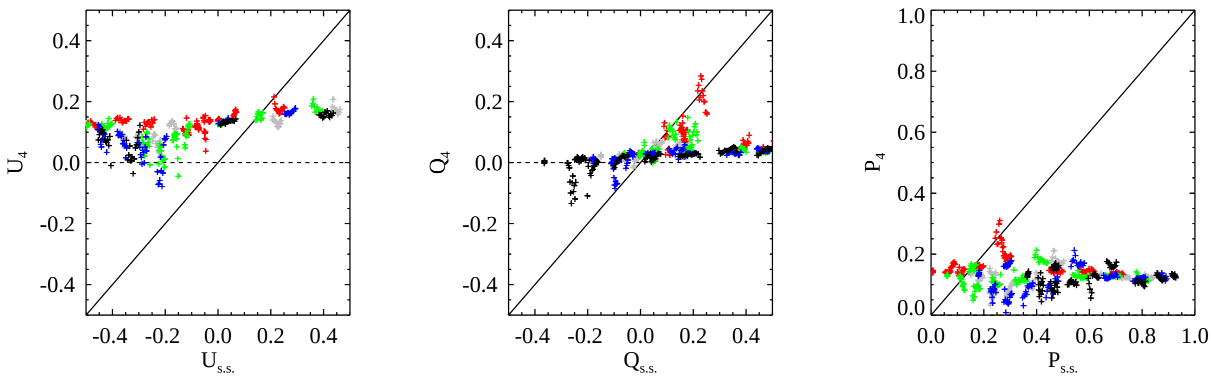

Fig. 1. Left: derived U_4 versus $U_{s.s.}$ with different colours indicating different scanning angles from east to west: red, green, blue, and black. The backscan pixels are grey. The vertical dashed line indicate the U_4 = 0 while the sloped line indicates U_4 = $U_{s.s.}$. Only the U-range containing measurements is shown for clarity. Middle: Similar as left panel but for Q_4 as a function of $Q_{s.s.}$. Right: Similar as left panel but for P_4 as a function of $P_{s.s.}$. Note that P has different axis ranges.

while $\mu 2_i^D$, $\mu 3_i^D$, $\mu 2_i^P$, and $\mu 3_i^P$ describe the radiance response of the main channel to Q and U, and of the PMD to Q and U, respectively. Equation 1 is often referred to as the PMD virtual sum. The PMDs 1-6 measure mostly Q, but due to polarisation mixing in the optics [3] they are also sensitive to U (i.e. $\mu 3^P$ is small but not zero), while for PMD 7 this sensitivity is reversed.

As already shown in [2], the PMD images resemble MODIS (onboard the TERRA satellite of NASA) images in great detail. Apparently the PMD measurements do reliably reproduce structures visible in the Earth atmosphere, however their absolute value might still be off. This might be due to wrong dark-current correction as in previous versions of the PCA this problem has occurred. The current dark-currents are under investigation at the moment.

3.1. Polarisation fraction from PMD 4 & 7

PMDs 4 and 7 are constructed to cover roughly the same wavelength region, but with a different polarisation sensitivity. The combination of these two PMDs (and thus two virtual sums) allows the PCA to determine both U and Q at the same time for this wavelength range. The left and middle panel of Fig. 1 show the values of U and Q (as determined from the combination of PMD 4 & 7), respectively, as function of the theoretical Q and U. In this report we indicate values determined from the combination of PMD 4 and 7 only with the subscript 4 for clarity. The vertical dashed lines indicate the Q = 0 or U = 0 line while the slope indicates where the fractional polarisation value equals the theoretical single scatter polarisation value. In most cases (except for sun-glint, rainbows, etc.) this is an extreme value as multiple scattering and clouds decrease the amount of polarisation. As such, realistic measurements should be between the no polarisation (Q, U = 0) and single scatter lines (lower-left and upper-right quadrants). In the right-hand panel of Fig. 1 the total measured degree of polarisation P, with P=$\sqrt{Q^2 + U^2}$, is shown against the theoretical single scatter value. Again realistic polarisation is expected to be smaller than the single scatter polarisation (lower-right quadrant). As can be seen in Fig. 1 U_4 and P_4 show an unphysical offset from zero and many measurements have unrealistic values (being in the wrong quadrant). This immediately makes clear that Q and U values currently determined from PMD 4 and 7 cannot be trusted.

3.2. Polarisation fraction from PMD 1 & 2

In order to find both Q and U for all other PMDs, an assumption about one of the two has to be made, as both cannot be solved simultaneously from a single measurement. The common approach in the PCA is to use a pre-defined ratio between Q and U (U/Q ratio) and replace U in the virtual sum with Q times this ratio. At the moment of this report PMD 1 and 2 use the theoretical single scattering ($U/Q_{s.s.}$) ratio. There is an exception for very small $Q_{s.s.}$ because then the ratio ($U/Q_{s.s.}$) might explode due to measurement errors. In these cases U is directly determined from $U_{s.s.}$ [3]. Fig. 2 and Fig. 3 show U, Q and P from PMD 1 and 2, respectively, in similar display as Fig. 1. The values behave much more

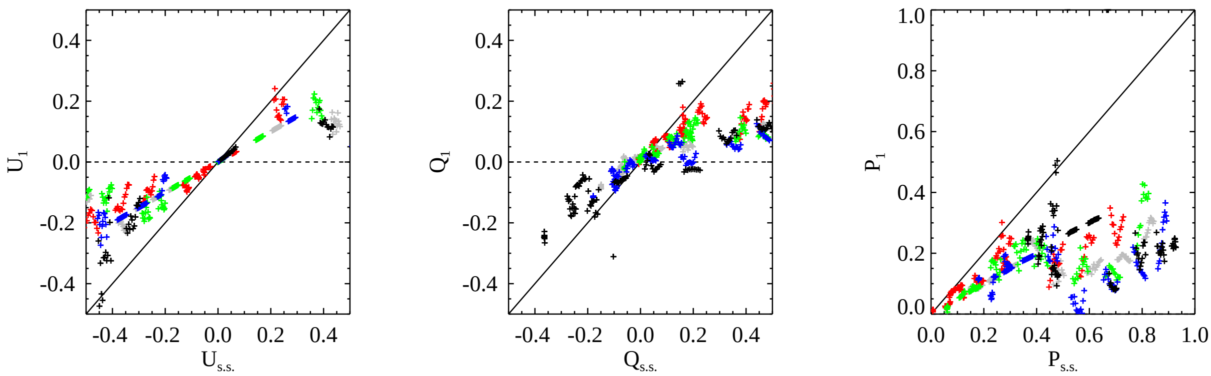

Fig. 2. Same format as Fig. 1 but for U_1, Q_1 and P_1.

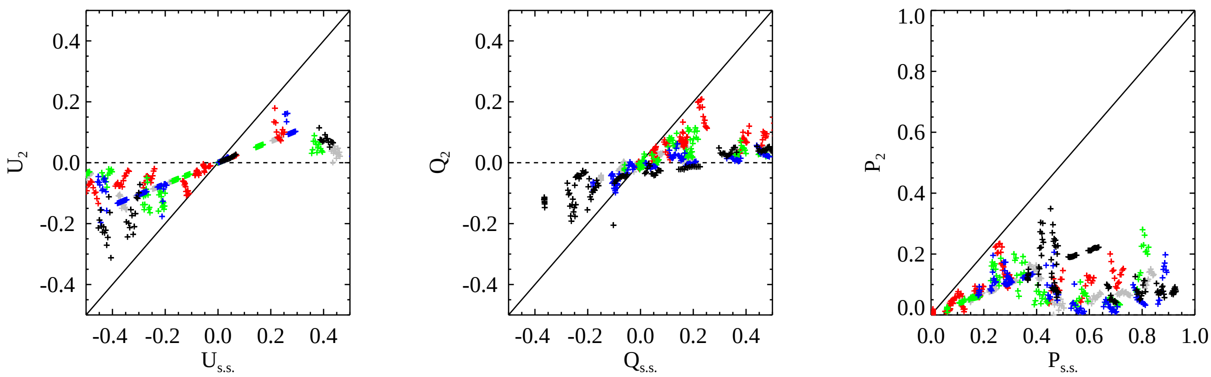

Fig. 3. Same format as Fig. 1 but for U_2, Q_2 and P_2.

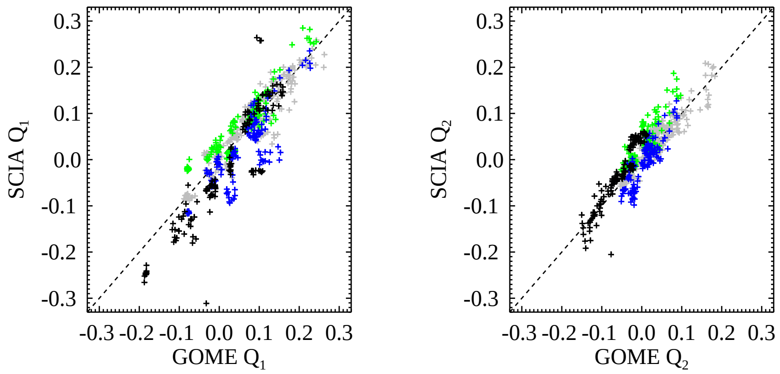

Fig. 4. Left: Q_1 as determined by GOME (interpolated to SCIAMACHY geolocations) versus Q_1 as determined by SCIAMACHY. Colours are the same as in Fig. 1. Again only the area containing measurements is shown for clarity. The dashed line indicates the case $Q_{GOME} = Q_{SCIA}$. Right: Same as left plot but for Q_2.

natural, only a few points are outside the normal quadrant but this is within the measurement uncertainty (0.05) [3]. The apparent line visible in the U measurements are from the direct interpolation from $U_{s.s.}$.

The GOME instrument onboard the ERS-2 satellite of ESA [4] measures Q at similar wavelengths allowing a direct comparison. There is a 30 min delay between observations and a different instrument, which both cause a small change in viewing geometry. Also GOME measures only Q, while SCIAMACHY is sensitive to both Q and U. As such one can only expect a roughly similar behaviour, not a one-on-one correlation. Comparing GOME with SCIAMACHY as in Fig. 4 shows that the measured values are indeed correlated for Q_1 and Q_2.

3.3. Polarisation fraction from PMD 3

Instead of the theoretical $U/Q_{s.s.}$, the U/Q ratio used for PMD 3 is an interpolation of $U/Q_{s.s.}$(at 298 nm) and U/Q_4 (at 854 nm) to the central wavelength of PMD 3 (661 nm). In the PCA an exception is made when Q_4 is very small (less than 0.1) as the ratio U/Q might explode due to noise on the measurements. In these cases U_3 (instead of the ratio U/Q) is directly interpolated between $U_{s.s.}$and U_4. As shown, U_4 and Q_4 are clearly unphysical, so one cannot trust any interpolation using these values. Indeed U_3 has many unphysical values (not shown here). Therefore one cannot trust Q_3 and U_3 as determined from PMD 3.

3.4. Polarisation fraction from PMD 5 & 6

For PMD 5 and 6 the U/Q ratio determined from PMD 4 and 7 is used. As mentioned, U_4 and Q_4 are clearly unphysical and thus also their ratio $U/Q_{s.s.}$. This means that a wrong ratio is used to determine Q (and U by multiplying Q with the used U/Q ratio) resulting in many unphysical values (not shown here).

4. POLARISATION FRACTION FROM CHANNEL OVERLAPS

The determination of the fractional polarisation from the main channel overlaps does not use the signal directly but instead uses the reflectivity, i.e. the (calibrated) signal compared to the Sun Mean Reference spectrum. Similar to the PMD (except for the combination of PMD 4 & 7) the PCA must use a U/Q ratio ($U/Q_{s.s.}$for overlap 1/2 en 2/3, U/Q_4 for overlap 3/4, 4/5, 5/6) in order to solve Q and U. All the polarisation values from the channel overlaps show clearly unphysical behaviour (not shown here).

5. INTEGRATION TIMES

To determine the fractional polarisation the PCA needs, along with the PMD measurements, also the main channel measurements that overlap in wavelength with the PMDs. Each SCIAMACHY main channel wavelength cluster has its own integration time, often varying between 0.25, 0.5, and 1 sec, while the PMDs are read out at 40Hz (and later down-sampled to 32Hz). The current version of the PCA has an implementation problem with the extrapolation from the longer to the shorter integration times for clusters. As such, at this time, only values for the longer integration times (1 sec) can be ”trusted”, while the shorter integraion times values are either completely wrong or zero. (This problem will hopefully be solved in the near future.)

6. CONCLUSIONS

All the fractional polarisation measurements determined by the SCIAMACHY PCA show clearly unphysical values except those from PMD 1 and 2. Comparing the Stokes parameter Q, as determined from these two PMDs, with the values measured by GOME shows a correlation. No satisfying explanation has been found yet for the problems with the other polarisation determinations (PMD 3 to 7 and main channel overlaps). Tests using the $U/Q_{s.s.}$ ratio for all PMDs instead of the clearly wrong ratio from PMD 4 and 7 show an improvement, but some of the offsets remain, indicating other problems. As such there is an open investigation to instrumental effects correction of the PMDs and implementation errors in the PCA.

REFERENCES

1. Van de Hulst H.C., *Light scattering by small particles*, Dover publications inc., New York, 1981.
2. Tilstra L.G., de Graaf M., Stammes P., First Verification of Sciamachy’s Polarisation Measurements, *Envisat Calibration Review Proceedings*, ESA Special Publication SP-520.
3. DLR, *SCIAMACHY Level 0 to 1c processing: Algorithm Theoretical Basis Document (ATBD)*, Dec 14, 2001.
4. Burrow J.P., et al. The global ozone monitoring experiment (GOME): mission concept and first scientific results. *J. Atmos Sci.*, 1999, **56**, 151-175.