FIRST VERIFICATION OF SCIAMACHY'S POLARISATION MEASUREMENTS

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ABSTRACT

We present a preliminary report on the verification of the SCIAMACHY level 1 polarisation product. The polarisation obtained from the PMD channels is necessary to correct for the dependence of SCIAMACHY on the polarisation of the detected radiation. As it turns out, the signals of the PMD channels behave rather well and can additionally be used as a very useful tool for imaging the Earth's surface. However, the fractional polarisations, necessary for the polarisation correction, show large errors. A possible explanation is given.

1. SCIAMACHY'S PMD CHANNELS

For the purpose of correcting the measured radiances for the polarisation of the detected light, the polarisation is measured for a number of wavelengths by Polarisation Measurement Devices (PMDs). They are listed in Table 1. Note that most PMDs only measure the Stokes parameter Q, but that the combination of PMDs 4 and 7 determines Q and U at roughly the same wavelength. As a useful addition, the polarisation (Q and U) can be calculated very accurately for wavelengths below, say, 300 nm. In this regime, a single scattering model can give an adequate description of the processes that, in this case, occur mostly in the top layer of the atmosphere [1]. In Table 1 these theoretical model values are denoted as 'measurements' coming from 'PMD 0'.

The ratio U/Q is known to be to a high degree independent of wavelength. Using this fact, the model value below 300 nm is assumed to be also valid for PMDs 1, 2, and 3. For PMD 4 and 7 the ratio is not important because Q and U are both being measured, but the ratio is used for the calculation at PMDs 5 and 6. Here, the ratio is determined by extrapolation to the wavelengths in question. This way, the data product is able to report Q and U for all wavelengths mentioned in Table 1. The last step in making the polarisation correction possible is an interpolation of the polarisations mentioned in Table 1 to all wavelengths that are covered by the normal spectral channels of SCIAMACHY. In general the level 2 products depend on the validity of this correction.

Table [1]: SCIAMACHY's PMD channels, the Stokes parameter that is effectively being measured (Q or U), the central wavelength, and the wavelength range that is being covered by the respective PMD channel. A theoretical model value (denoted '0') can be calculated as well, for wavelengths below 300 nm where a single scattering model without surface reflection suffices.

PMD	**'0'**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Stokes par.	Q, U	Q	Q	Q	Q	Q	Q	U
λ (nm)	298	344	487	661	853	1577	2322	854
$\Delta\lambda$ (nm)	—	67	75	88	95	137	115	103

2. PMD IMAGING

Figure 1 presents a first verification result of the PMD signals. The data was recorded on August 2, 2002 (orbit 2209) and the state shown is a nadir state. The image was made using the intensities of PMD channels 2, 3, and 4. Each ground pixel of the (nadir) state was given a specific 'RGB' colour, the red, green and blue components of which were determined from the recorded intensities of PMDs 3, 4 and 2, respectively. A first conclusion is that the ground and clouds are both recorded satisfactorily. The gaps along the scan-direction are there because we have not plotted the backscan pixels.

The size of the pixels in Figure 1 is 30 by 60 kilometres. Figure 2 presents the same state, but now we have improved the resolution to 30 by 7.5 kilometres. To achieve this, we have used all the individual PMD values, and not those that were binned together to the size of the overlapping spectral channels pixels. Also, the ground pixels were stretched along the flight direction to fill the gap between consecutive forward scans. The images obtained in this way are all of a high quality, and with a high degree of contrast, which indicates that the PMD channels are operating reliably.

Next we present a few PMD images to report on the ability of these images to produce accurate images of clouds that are monitored during nadir states. Figure 3 presents an image of two SCIAMACHY nadir states. Figure 4 presents the MODIS image of the same area that was taken at about the same time. (MODIS is on board the TERRA satellite of NASA, which is in a 10:30 UTC orbit.) When we compare both images, it is clear that the PMD image contains all the major cloud features that are found in the MODIS image. Another example is given in the combination of Figures 5 and 6. This

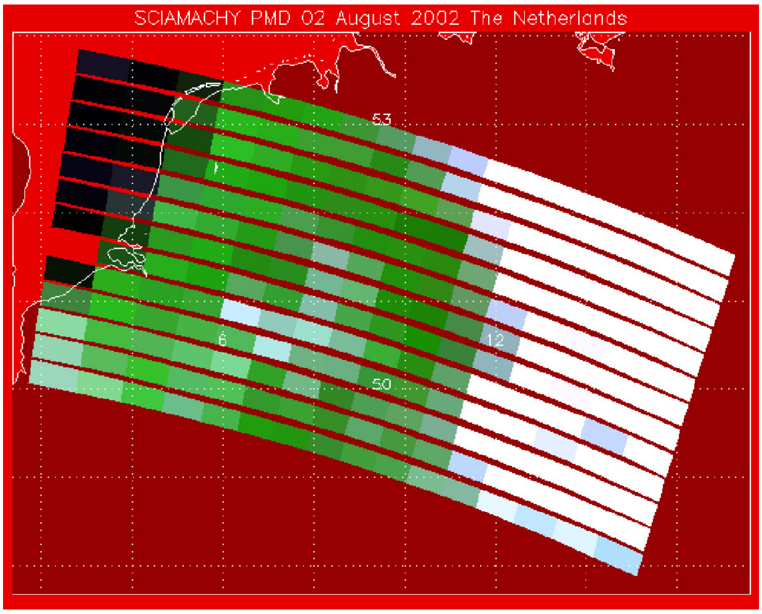

Fig. 1: Image obtained by mixing the signals associated with three PMD channels (PMDs 2, 3 and 4 listed in Table 1) to the colours presented. The data (orbit 2209) was taken on August 2, 2002, with SCIAMACHY crossing the Netherlands. Backscan pixels are not displayed as they mess up the picture. The spatial resolution is 30 by 60 kilometres.

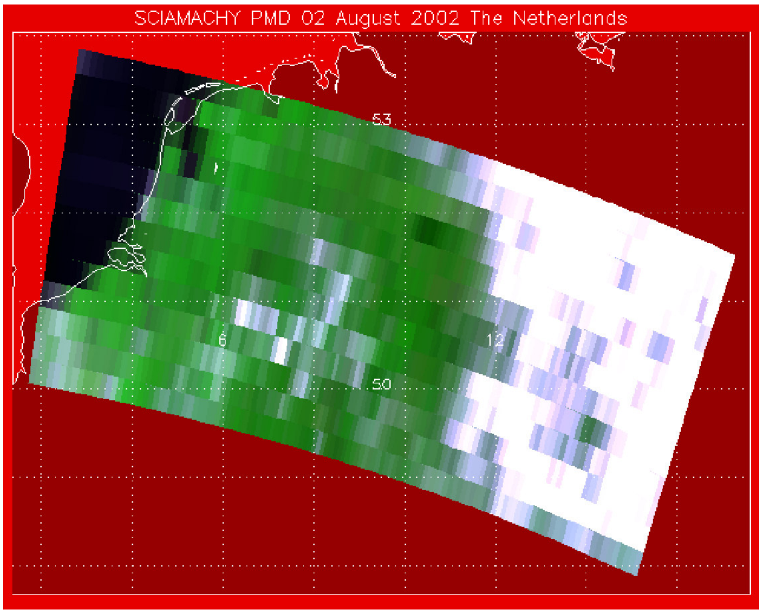

Fig. 2: The picture relates to the same state as in Figure 1 but now the spatial resolution has been increased by using all the *individual* PMD measurements, and not those that were binned together and presented as such in the data product. The resolution now amounts to 30 by 7.5 kilometres. The pixels have furthermore been stretched to remove the gaps in between scans.

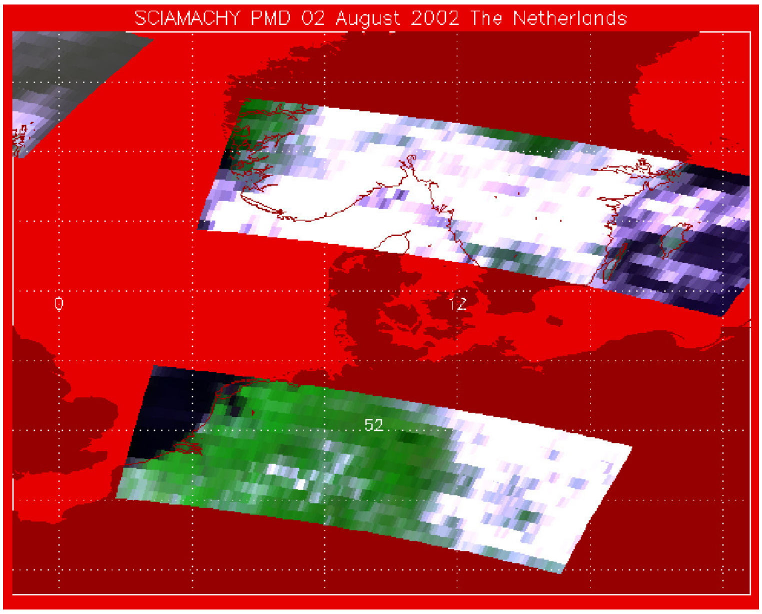

Fig. 3: Image of two nadir states over Norway/Sweden, and over the Benelux countries and Germany. The second state is the same state as shown in Figures 1 and 2. The MODIS picture, taken at about roughly the same moment in time, is given in Figure 4 for comparison. The spatial resolution was again extended to 30 by 7.5 kilometres.

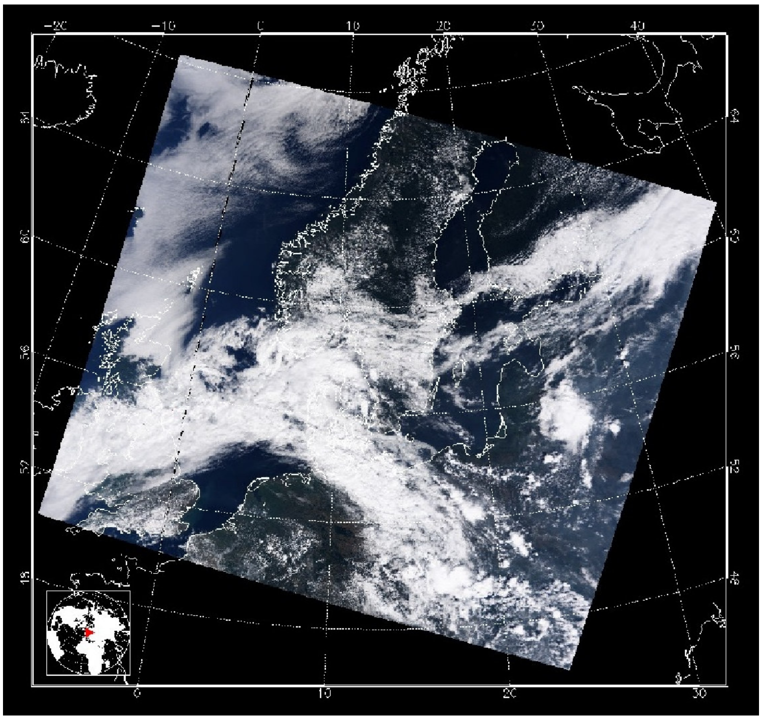

Fig. 4: MODIS picture of the same region, and taken in approximately the same time frame as the two states in Figure 3. Comparing both figures, it is clear that the PMD channels are able to monitor clouds and ground surface with great accuracy.

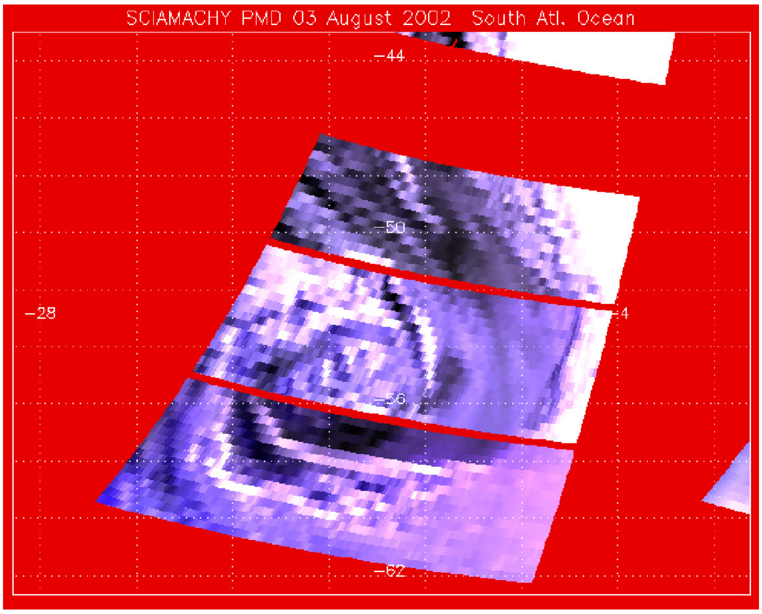

Fig. 5: SCIAMACHY crossing the South Atlantic ocean on August 3, 2002. The three adjoining states are all nadir states coming from orbit 2223. According to our PMD image, there is a strong depression located at the scene. This picture is confirmed by a MODIS image taken at approximately the same moment in time (cf. Figure 6).

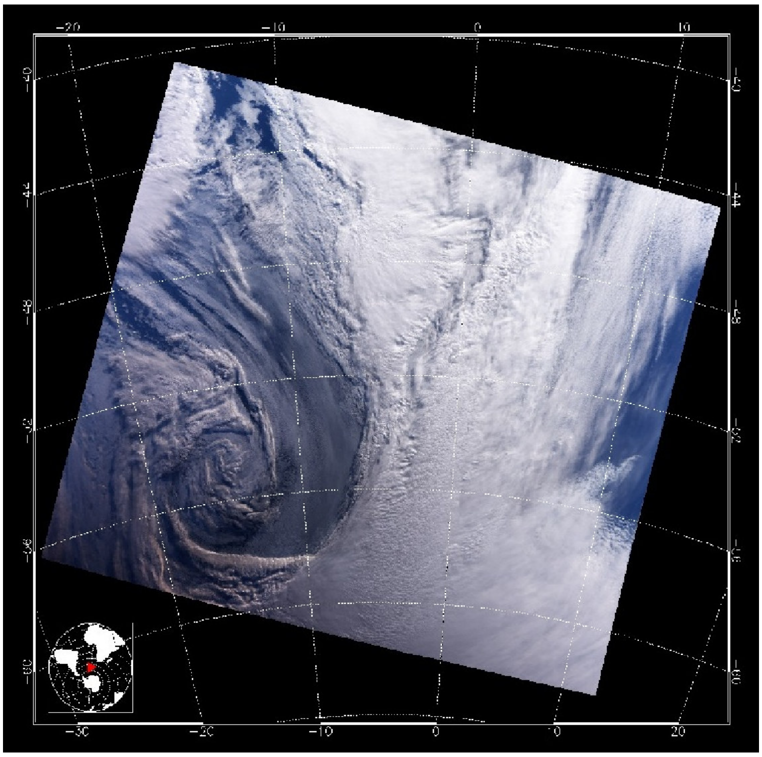

Fig. 6: MODIS image of the South Atlantic ocean, for comparison with Figure 5. Notice that the SCIAMACHY image resembles the MODIS image in great detail. There do not appear to be any bad pixels in all three states. Apparently, the PMD signals are reliable.

time the monitored location is in the South Atlantic ocean. Obviously, the images agree well with one another regarding the strong depression that was present over the South Atlantic ocean. In conclusion, the PMD channels appear to function well and can be used for cloud and surface imaging.

3. FRACTIONAL POLARISATION

Figures 7 and 8 present the fractional nadir polarisation Q/I as a function of Latitude, for the theoretical model value (below 300 nm) and for PMDs 1 to 6, respectively. In both figures we have employed the use of colours to distinguish between east pixels (red), center-east pixels (green), center-west pixels (blue) and west pixels (in black). Notice that each state can have a different number of these pixels. The (theoretical) Q/I completely agrees with our own calculations where we used the line-of-sight zenith angle θ, the solar zenith angle θ_0 and the azimuths ϕ and ϕ_0 from the data product.

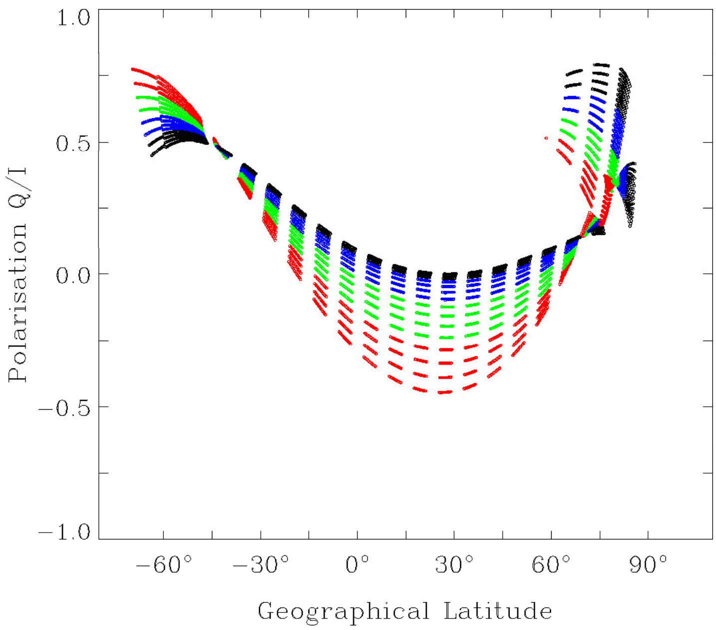

Fig. 7: Theoretical fractional polarisation Q/I from the data product as a function of Latitude. Orbit 2209 of August 2, 2002. Different colours indicate different scan angles: red, green, blue and black colours correspond to east, center-east, center-west and west pixels, respectively.

The plots for PMDs 1 to 6, however, show a disturbing result. First of all, a large number of pixels provide a zero value. Secondly, the gaps in the middle for PMDs 3 and 4, around $Q/I = 0$, are physically illogical, and similar jumps appear for the other PMDs as well. Note that in both figures we have only presented values of Q/I. Unfortunately, the U/I of the data product do an even worse job. The same type of errors as for the Q/I occur, but worse, and additionally, some values (about 3% of all PMD values) lie outside the interval $[-1,1]$, which clearly is a non-physical type of behaviour. These facts are summarised in Figure 9, where the U/I determined by PMD 7 is plotted along the orbit. Notice the similarity between PMDs 4 and 7.

The effective PMD wavelengths, which are also part of the data product, show a lot of zero values. Whenever a wavelength is non-zero, however, the wavelength appears to be reliable. Obviously, because the PMD signal seems reliable, judging from the PMD images that were presented, there is a problem with the calculation of the fractional polarisation. Furthermore, we note that the polarisations obtained from the overlap regions are all zero in the data product. The attempt to obtain the polarisation in this way thus fails completely.

4. EXPLANATION OF ERRORS

Most likely, the errors can be explained by an error in the theoretical values of the U from the data product. To be more precise, there appears to be an occasional (but frequent) sign error in U. This is more or less illustrated in Figure 10, where we have plotted U/Q as a function of the relative azimuth $\phi - \phi_0$. The green dots are the U/Q of eastern pixels, the red dots relate to west pixels and the blue dots correspond to $\tan 2\chi_{ss}$, which is the proper, theoretical single scattering value of the ratio, and which has been calculated using the θ, θ_0 and $\phi - \phi_0$ supplied by the data product. The pixels plotted in Figure 10 furthermore all have $|\theta| < 2.1°$, which makes them pretty much resemble exact nadir pixels. Obviously, the value of U/Q is sometimes presented with the wrong sign.

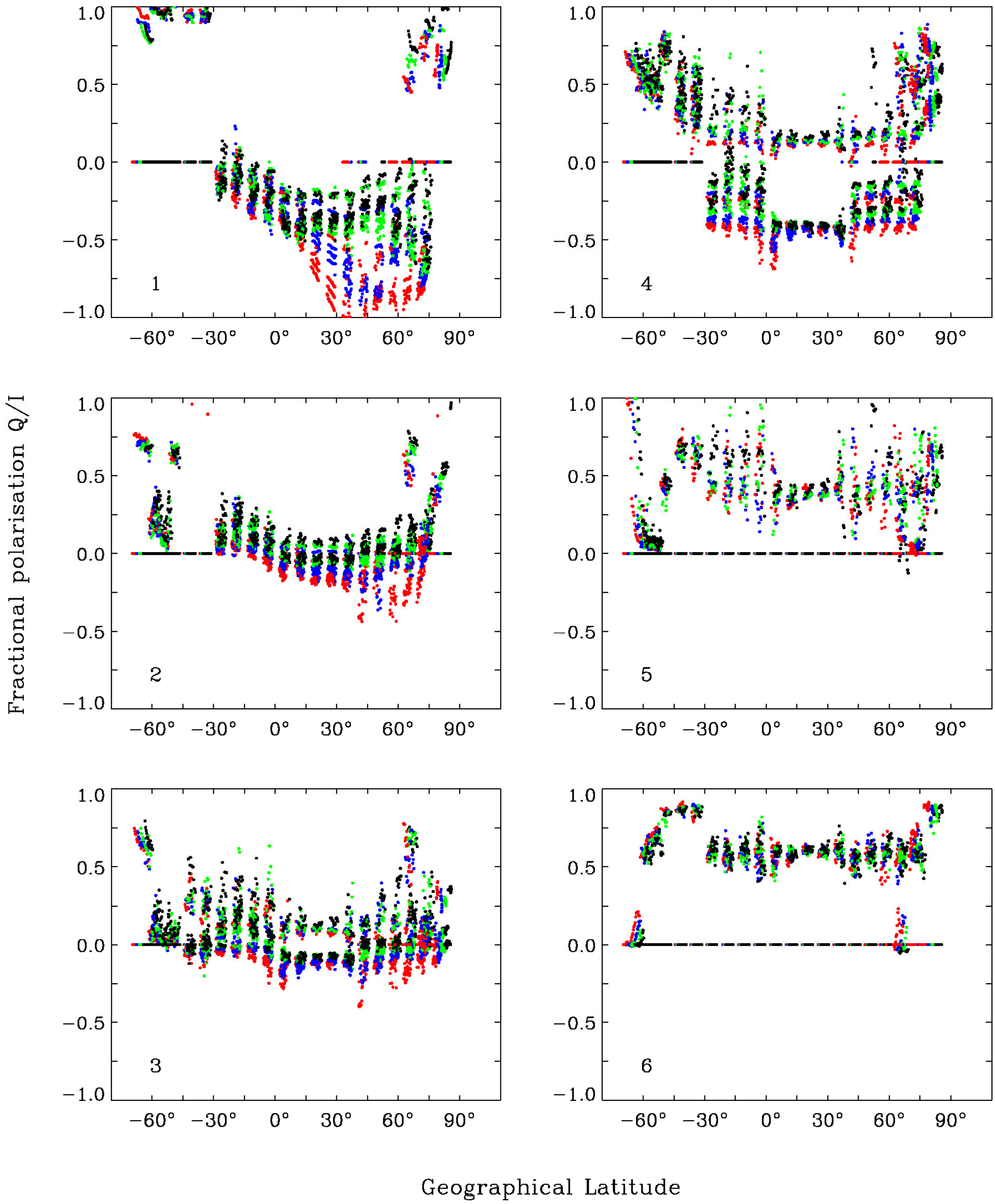

Fig. 8: Q/I for PMDs 1 to 6. The result appears non-physical, with gaps, jumps, and a lot of zero (misleading) values along the orbit. Orbit 2209, August 2, 2002. The labels refer to the PMDs in question. The colours used in the plot have the same meaning as in Figure 7.

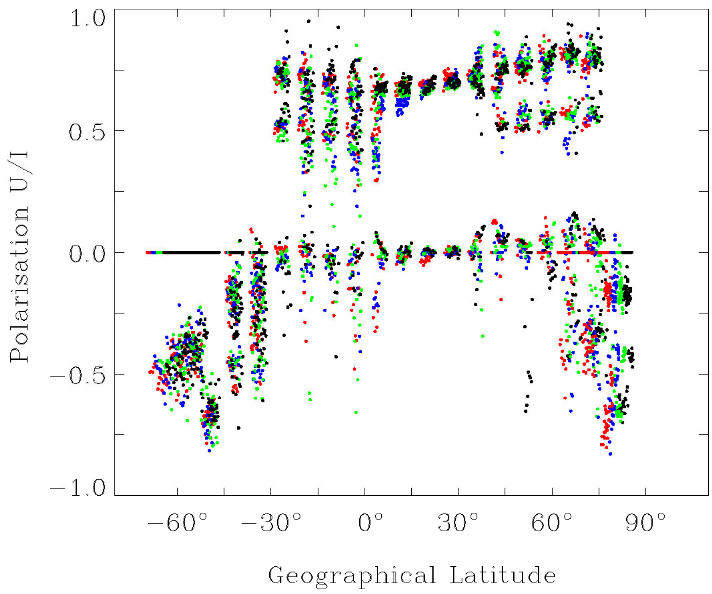

Fig. 9: Fractional polarisation U/I determined by PMD 7 as a function of Latitude, for orbit 2209. Notice the similarity with PMD 4 in Figure 8. The same colour code as was used in Figure 7 applies.

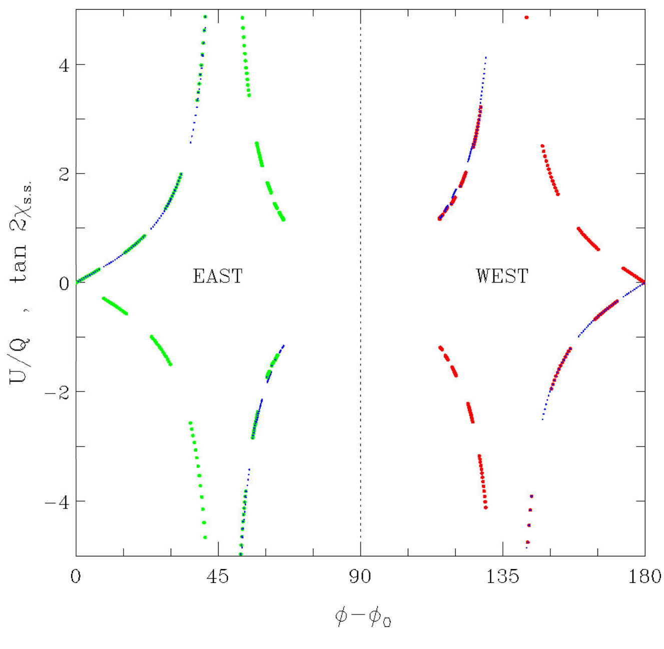

Fig. 10: The ratio U/Q as a function of $\phi - \phi_0$, for near nadir pixels ($\theta \approx 0°$). Green and red dots represent the theoretical U/Q obtained from the data product. The blue points are presenting $\tan 2\chi_{ss}$ as calculated from θ, θ_0 and $\phi - \phi_0$. The ratio for near-nadir viewing geometries should equal $\tan 2(\phi - \phi_0)$. Obviously, about half of the pixels show the wrong sign. Orbit 2209.

As for the particular choice for 'near-nadir' pixels, some calculus shows that for near-nadir pixels, the ratio U/Q can safely be approximated into the very simple equation [2]

$$U/Q = \tan 2\chi_{ss} \approx \tan 2(\phi - \phi_0), \tag{1}$$

which means that by choosing near-nadir pixels, we have eliminated θ and θ_0 as factors of influence. Still, the theoretical U/Q from the data product does not always match the blue curve. Thus the only parameter that can with certainty be held responsible for the sign error in Figure 10 is the relative azimuth $\phi - \phi_0$. The individual values of ϕ and ϕ_0 seem to be correct, however, so it is the difference, or the use of ϕ and ϕ_0 in the algorithm that must be causing the errors. When we produce the same type of plots of U/I for the PMDs, we find the same type of behaviour, which is logical because the model values for Q/I and U/I are used in the calculation of the Q/I and U/I of the PMDs [3]. A sign error in the U model values thus translates into similar errors for the PMD values of U/Q.

5. CONCLUSIONS

The set of imaging pictures we presented in this report clearly show that the PMD signals are reliable and stable. Yet, at the same time, the fractional polarisations obtained from the PMD signals show large errors. These errors presumable arise from a wrong usage of $\phi - \phi_0$ in the software used to calculate the fractional polarisations. The errors in the fractional polarisation unfortunately also cause the polarisation calibration to fail.

6. REFERENCES

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