MODIS Prelaunch Polarization Factor

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1 Abstract

The prelaunch polarization measurements of MODIS Aqua and Terra are contaminated by a four-cycle effect in some bands. To extract the desired 2-cycle effect, a Fourier transformation was suggested by SBRS [1]. Presumably, this method has been applied by Miami. MCST has derived the polarization parameters with a least-squares fit. The derived polarization factors differs by a factor of 2 from Miami, with MCST values being larger. In this report, Fourier transformation and linear regression are applied to derive the polarization parameters for Aqua. The results from the linear regression agree well with the MCST results, the results from the initial Fourier transformation agree well with the Miami results. The results from the linear regression describe the measurements much better than the results from the Fourier transformation. The mistake in the initial Fourier transformation is described.

The output quantity compared between the different methods in this report is the polarization factor. This may seem strange, since the quantity used for the polarization correction in the L2 code are the coefficients am12 and am13. However, the coefficients am12 and am13 depend on the setup of MODIS relative to the polarizer during the prelaunch measurements, an issue not yet completely resolved at the time of the writing of this report. The polarization factor is independent of this setup. If the polarization factors do not agree, the coefficients am12 and am13 cannot agree either. The polarization factor is averaged over detectors for comparison purposes (MCST provided the polarization factor only averaged over detectors).

2 Methods

This report focuses on MODIS band 8, mirror side 1, but the results apply to all MODIS bands and both mirror sides.

2.1 Fourier analysis

The 2-cycle component was extracted from the measurements by Fourier transformation:

1. A Fourier transformation was applied to the measured data using the IDL 'FFT' routine.

2. Only the constant term and the second order coefficients were used to perform an inverse Fourier transformation. (Section 4 will show that more coefficients are needed).

3. The regress routine was used with two basis functions, $\cos(2 \cdot \theta)$ and $\sin(2 \cdot \theta)$, where θ is the rotation angle of the polarizer in the prelaunch measurement setup. The coefficients of the two basis function were derived by performing a linear regression against the results of the inverse Fourier transformation. These coefficients are the coefficients am12 and am13 to be used in the polarization correction LUT. In theory, the coefficients am12 and am13 are the second order Fourier coefficients determined above, so steps 2 and 3 seem unnecessary. Unfortunately, the IDL Fourier transformation routine (FFT) applies a complicated normalization to the Fourier coefficients, so it was chosen to avoid this problem using the linear regression approach.

2.2 Linear regression

The fitting routine 'regress' from IDL was used to apply a multiple linear regression directly to the measured data, using the two basis functions (called 'independent variable data' in the IDL help routine) described above.

2.3 Polarization Factor

The methods presented in sections 2.1 and 2.2 each yield coefficients am12 and am13. The polarization correction $y(\theta)$ to be used in the L2 code has the form:

$$y(\theta) = 1.0 + am12 \cdot \cos(2 \cdot \theta) + am13 \cdot \sin(2 \cdot \theta) \quad (1)$$

The polarization factor P_f (called polarization magnitude by Miami) was calculated as

$$P_f = \sqrt{am12^2 + am13^2} \quad (2)$$

if the coefficients am12 and am13 were available (MCST did not calculate these coefficients, but determined the polarization factor by a comparable method, see [2]). The definition of polarization factor here is equivalent to that in [2] [1]. It also reproduces exactly the quantity called 'polarization magnitude' in the LUT for Aqua provided by Miami using the coefficients am12 and am13 from that LUT, so we can assume that the two definitions are equivalent. However, this assumption does not influence the results of this report, since the Miami definition is not used in this report. The definition used here is also used in [1], but it is *not* the same as the often used ratio of the difference between maximum and minimum signal over the sum of maximum and minimum signal.

3 Results

The prelaunch polarization measurements for MODIS Aqua are shown in Fig. 1. The polarization correction derived from Fourier transformation is shown as a dashed line in the right hand plot (using the constant and second order Fourier coefficient only), the polarization correction derived from linear regression is shown as a solid line in the left hand plot. It can be seen that the later gives a better fit to the data. The solid line in the right hand plot shows the polarization correction derived from all coefficients of the Fourier transformation *except* for the second order coefficient. Obviously, these coefficients capture a lot of the variability of the prelaunch measurements, in effect about as much as the second order coefficient itself. Table 1 shows the polarization factors for Aqua and Terra. The polarization factor for Aqua calculated with the (wrong) Fourier transformation by the SeaWiFS group is lower by about 50% than the MCST value, and agrees qualitatively with the value from Miami. The polarization factor calculated with the linear regression agrees perfectly with the MCST value.

4 Discussion

The obvious question is: why do Fourier transformation and regression produce different answers? This section shows the mistake made in the Fourier transformation in section 2. Miami should

[1] The quantities P_f, am12 and am13 in this report correspond to the quantities a_{BD}, u_1 and u_2, respectively, in [2].

Source	MCST	Miami	SeaWiFS (Fourier, wrong))	SeaWiFS (Fourier, revised)	SeaWiFS (regression)
P_f Terra	0.0351	0.0178			
P_f Aqua	0.0342	0.0165	0.0171	0.0342	0.0342

Table 1: The polarization magnitude P_f for band 8 (averaged over detectors, mirror side 1, AOI on scan mirror of 15.5°, corresponding to a MODIS viewing angle of $-45°$), for Aqua and Terra, calculated by MCST, Miami, and the author of this report (SeaWiFS group). Source for MCST are MCST internal memo's from 5/10/2000 and 1/10/2002 and associated files. Source for Miami are HDF files (coefficients am12 and am13 in modis-pol-corr-aqua-1a.hdf for Aqua, in modis-pol-test-6a.hdf for Terra). 'Fourier, wrong' and 'regression' are the methods described in section 2, 'Fourier, revised' is the method described in section 4.

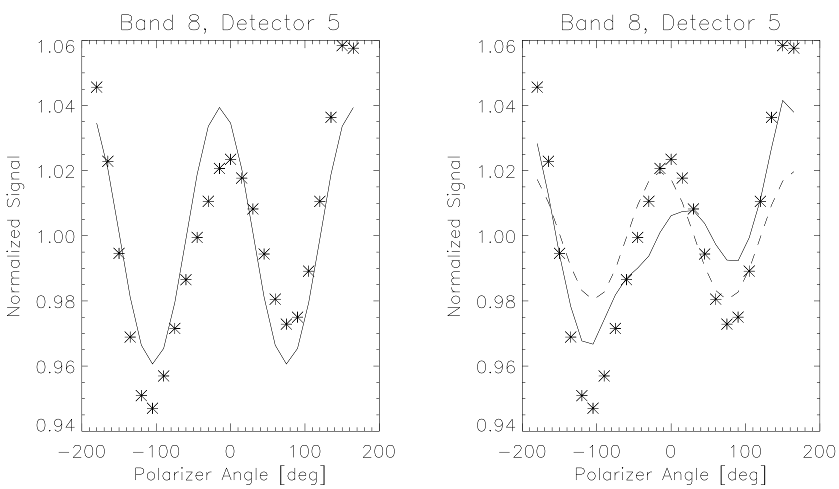

Figure 1: The stars show the MODIS Aqua band 8, detector 5 prelaunch polarization measurements in both plots. The solid line in the left hand plot shows the results of a linear regression of the two basis functions described in the text. The right hand plot shows the results of the Fourier transformation: the dashed line shows the constant and the two-cycle component, the dashed line shows all components except the two-cycle component.

reexamine what method was used in their calculations. Since their polarization factors agree qualitatively with the polarization factors derived here with the Fourier transformation described in section 2 (see table 1), it is possible they made a similar mistake.

The stars in Fig. 2 show the real and imaginary parts of the Fourier coefficients derived in section 2. It can be seen that not only the second order coefficients are significant, but also the second to last coefficients have a similar magnitude. IDL computes Fourier coefficients for positive **and negative** frequencies. This was not clear to the author of this study until recently. The frequency of the second to last coefficient corresponds to the negative of the frequency of the second coefficient. Fig. 3 shows the difference of the inverse Fourier transformation using only the second coefficient in the left plot, and using both the second and second to last coefficient in the right plot. The later method is obviously the correct method to derive the two-cycle pattern, and the polarization factor calculated with this method is shown in table 1 in the column 'Fourier, revised'. It agrees perfectly with the values from the regression method and the MCST value.

References

[1] Young, J., Knight, E., Merrow, C., SPIE Conference on Earth Observing Systems III, San Diego ,California, July 1998, SPIE Vol. 3439, 247-256

[2] Xiong S., Sun J., Xiong J., MODIS FM1 Pre-Launch Polarization Test Data Processing and Analysis, MCST Internal Memorandum, October 2002

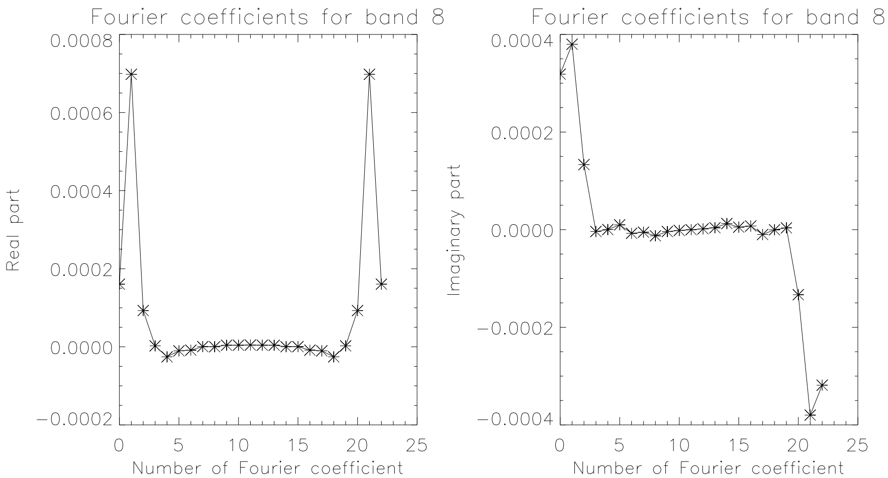

Figure 2: The stars (connected by a solid line) show the Fourier coefficients (real parts on the left, imaginary parts on the right) for band 8, detector 5. 1 on the x-axis corresponds to second order Fourier coefficient, 21 is the second to last Fourier coefficient returned from IDL. The constant term (0 order Fourier coefficient) is not plotted.

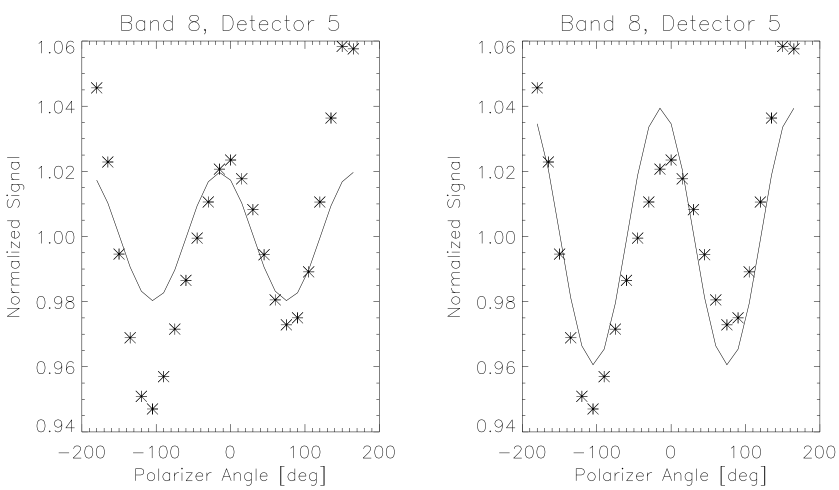

Figure 3: The stars show the measurements for band 8, detector 5. The solid line on the left shows the results from the inverse Fourier transformation using the constant and second order Fourier coefficient only, the solid line on the right shows the results from the inverse Fourier transformation using the constant, second order and second to last Fourier coefficient.