New Polarization Correction for MODIS Aqua Ocean Color: Recent Results and Remaining Challenges

Gerhard Meister, Bryan Franz, Ewa Kwiatkowska, Gene Feldman, Charles McClain
Ocean Color Discipline Processing Group, Goddard Space Flight Center

1. Background

The top-of-atmosphere (TOA) radiances (I) leaving the earth are partially linearly polarized. The Stokes vector for partially linearly polarized light with polarization direction $\theta$ and degree of polarization $P$ is given by

$I_\theta = I_0 \cos^2 \theta + I_\perp \sin^2 \theta$

The MODIS Aqua responsivity depends on the polarization of the measured radiances, this means the measured radiances $I_\theta$ is different from $I_\perp$. $I_\theta$ tends to be converted into $I_\perp$. The MODIS Aqua polarization sensitivity was characterized previously. A polarization filter was placed between a light source and the MODIS aperture and turned around its axis, varying the polarization direction from $-180^\circ$ to $+180^\circ$. The MODIS polarization sensitivity is a function of scan angle, so this procedure was performed at scan angles $-45^\circ$, $22.5^\circ$, $0^\circ$, $22.5^\circ$, and $+45^\circ$. Results for MODIS bands 8 (412nm) and 15 (748nm) are shown in Fig. 1 and 2 for nadir viewing. The expected result is a two-cycle variation proportional to $1 + m sin^2 \theta cos^2 \theta$. The MODIS MODIS Aqua polarization coefficients $m_{0}$ and $m_{12}$ are extracted from the fit.

The Stokes vector for partially linearly polarized light is defined by the components $I$, $Q$, $U$, and $V$, where

$I = I_\perp + I_\theta$

$Q = I_\theta - I_\perp$

$U = 2 \sqrt{I_\perp I_\theta} \cos \theta$

$V = 2 \sqrt{I_\perp I_\theta} \sin \theta$

The equation to convert the TOA radiance into the polarized components is

$I_\theta = \frac{I + m_{0}}{1 + m_{12}}$

where $m_{0}$ is a constant and $m_{12}$ is an artifact of the measurement setup that potentially obscures the two-cycle effect. The stars show the measurements, the solid lines show the fitted two-cycle variation. The MODIS MODIS Aqua polarization coefficients $m_{0}$ and $m_{12}$ are extracted from the fit.

1.8 Simulation

The degree of polarization $P$ and the polarization sensitivity of the TOA radiances increase with the angle of incidence on the MODIS scan mirror. It can be seen that for large viewing angles, corresponding to large angles of incidence on the MODIS scan mirror, the polarization sensitivity is highest for band 8, as it is for most other bands, but not for band 15.

Furthermore, the magnitude of the polarization coefficients was clearly wrong in most cases. These polarization coefficients produced dramatically different ocean color radiances for MODIS when compared to the SeaWiFS radiances. The OCDP group has produced several time series for Aqua (ATXN) and SeaWiFS. Specifically:

- AT06 contains polarization coefficients similar to the ones pre-2004
- AT15 contains polarization coefficients with correct magnitudes and angle definitions currently assumed to be accurate
- AT06 is still significant, but uses a different definition about angle definition in item 2).

The magnitude of $m_{13}$ is usually much smaller than the magnitude of $m_{12}$ (see Fig. 3), thus it is critical to be correct about item 1). The impact of item 2) is still significant, as can be seen by comparing the time series results below. The left column shows the radiances for SeaWiFS (solid line) and MODIS Aqua (dashed line). AT06, Band 1 corresponds to the 412nm band, Band 2 to 443nm, Band 3 to 488nm, and Band 5 to 550nm. The remaining radiances in the right column are the SeaWiFS ocean color time series. Plotted to the right are the AT06 and AT15 radiances, the blue line represents the SeaWiFS radiances, the orange line the AT06 radiances, and the green line the AT15 radiances. The difference between the SeaWiFS and AT15 radiances is always from $-150^\circ$ to $+170^\circ$. The AT06 radiances are spectrally consistent and not necessarily caused by polarization.

2. New Interpretation of Prelaunch Characterization

The MODIS prelaunch polarization characterization measurements are poorly documented regarding the angle of the rotating polarizer relative to MODIS. Specifically, it was not clear whether:

1) $P$ is on the polarization into the flight direction of MODIS or perpendicular to it, and
2) whether positive angles of the polarizer correspond to a clockwise or counterclockwise rotation.

The MODIS MODIS Aqua polarization coefficients $m_{0}$ and $m_{12}$ are extracted from the fit.

5. Outlook

The huge differences between the Aqua and SeaWiFS water-leaving radiances from the pre-2004 processing in high latitudes have been significantly reduced for the highly polarized bands with the new polarization correction. The remaining seasonal variations between Aqua and SeaWiFS up to 20% in normalized water-leaving radiances at high latitudes are spectroscopically consistent and not necessarily caused by polarization.

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3. Current Radiance Products

OCDC has a limited Aqua time series consisting of about 4 days out of each month to reduce computing time to evaluate the impact of calibration changes (e.g., polarization, pixel masking, ocean surface BRF, land thresholds, etc.) as well. The current best calibration algorithms are applied at AT15, some results are shown below. At this point, the agreement between SeaWiFS and Aqua is very good, and in neither whether remaining differences are due to the calibration of SeaWiFS, Aqua, or if they are geophysical.

It is interesting to look at the rations Aqua/SeaWiFS for seasonal means for the different latitudes of the Pacific small regions (40°S to 40°N, 10°W to 10°E) with latitudes in 10° steps (40°S to 40°N). The solar zenith angle does not change monotonically from north to south for these comparisons. If the ratios are plotted versus the average solar zenith angle (see Fig. 4), the trend emerges that the Aqua radiances decrease relative to SeaWiFS with increasing solar zenith angles, especially at 40°B and 40°N. This is not true for unknown. Possible reasons are the atmospheric correction, ocean surface BRF, or remaining polarization errors. The data points shown below are the ratios of the water leaving radiances for July and November.

4. Conclusions

The huge differences between the Aqua and SeaWiFS water-leaving radiances from the pre-2004 processing in high latitudes have been significantly reduced for the highly polarized bands with the new polarization correction. The remaining seasonal variations between Aqua and SeaWiFS up to 20% in normalized water-leaving radiances at high latitudes are spectroscopically consistent and not necessarily caused by polarization.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5: Degree of polarization

Fig. 6: Q component

Fig. 7: Polarization corrected $I_\theta$