CORRECTIONS TO THE CALIBRATION OF MODIS AQUA OCEAN COLOR BANDS DERIVED FROM SEAWIFS DATA

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1. INTRODUCTION

There are currently two units of the Moderate Resolution Imaging Spectroradiometer (MODIS)[1] orbiting the earth. The first was launched in December 1999 on NASA's Earth Observing System (EOS) Terra satellite, the second on the Aqua satellite in May 2002. MODIS has 36 spectral bands on four different focal planes. The Ocean Biology Processing Group (OBPG) at NASA uses bands 8-16 with center wavelengths from 412nm to 870nm to produce the standard ocean color data products[2]. The basic ocean color products are water-leaving radiances from bands 8-14 (412nm, 443nm, 488nm, 531nm, 547nm, 667nm, and 678nm). Bands 15 and 16 (748nm and 869nm) are used to determine the aerosol optical thickness and the aerosol type for atmospheric correction.

The OBPG is trying to achieve a relative stability of the radiometric calibration on the order of $\pm 0.2\%$, which surpasses the official requirements for the MODIS reflective solar bands (bands 1-19 and 26). The absolute reflectance factor uncertainty varies by band between 1.6% and 2.1%[3], and the stability is on the order of 0.5%. Thus the ocean color relative stability requirement is very restrictive, whereas an absolute calibration uncertainty of 5% is acceptable for the ocean color algorithms because most bands are vicariously calibrated[4].

Both MODIS instruments are calibrated using on-board calibrators[5] and lunar irradiances[6]. For MODIS Aqua, these calibration sources have been sufficient to produce high quality ocean color products[2] up to 2007. For MODIS Terra, this has not been the case[7]. The OBPG has developed a vicarious calibration method to improve the MODIS Terra characterization for bands 8-14, using SeaWiFS[8] water-leaving radiances as truth fields[9]. The same method was applied to MODIS Aqua. This paper presents the MODIS Aqua results using the latest MODIS and SeaWiFS calibration improvements. The most significant correction is needed at 412nm starting in 2007.

2. STANDARD MODIS CALIBRATION AND CHARACTERIZATION METHODS

The standard MODIS calibration equation[5] uses the calibration coefficient m_1 to describe changes in the radiometric sensitivity of the instrument. The m_1's are used to derive earth scene reflectance factors ρ_{EV} from the measured counts of the earth scene (dn_{EV}) with:

$$\rho_{EV} \cdot \cos(\theta_{EV}) = m_1 \cdot dn^*_{EV} \cdot d^2_{Earth-Sun} \tag{1}$$

where ρ_{EV} are earth scene reflectance factors, dn^*_{EV} are the temperature corrected measured counts, and $d_{Earth-Sun}$ is the distance between earth and sun, and θ_{EV} is the solar zenith angle. The scan angle dependence is modeled by dividing by the RVS (response-versus-scan). In the vicarious cross calibration process, we chose to simplify the calibration approach by combining the effects of m_1 and RVS into one scan angle dependent variable, M_{11}.

The calibration source for determining m_1 on-orbit is the solar diffuser. The solar diffuser is viewed at an angle of incidence on the scan mirror of $50.3°$. The calibration source for determining the RVS are lunar measurements through the space view

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port. The moon is viewed at an angle of incidence on the scan mirror of $11.4°$[10]. The radiometric response for all other angles of incidence is modeled, combining the solar diffuser, lunar, and prelaunch characterization measurements at various angles.

The standard polarization correction equation for an uncalibrated instrument[11] is

$$L_m = M_{11}L_t + M_{12}(Q_t cos2\alpha + U_t sin2\alpha) + M_{13}(-Q_t sin2\alpha + U_t cos2\alpha) + M_{14}V_t \tag{2}$$

where (L_t, Q_t, U_t, V_t) is the Stokes vector at the top-of-atmosphere (TOA), L_m is the measured radiance, and α is a rotation angle to adjust for different reference frames. Since V_t is very close to zero at the TOA, M_{14} is an irrelevant parameter for MODIS. The parameters M_{12} and M_{13} were determined prelaunch at scan angles from $-45°$ to $+45°$, for each band, mirror side, and detector[12]. The variations of these parameters with detector were considered suspect and not applied in the ocean color processing[13].

3. VICARIOUS CALIBRATION METHOD

The cross calibration method has been described by Kwiatkowska et al.[9], so here we provide only a brief summary. For a given day, the level 3 water-leaving radiances from SeaWiFS are used to predict the TOA radiances as seen by MODIS on that day, using the atmospheric correction approach from Gordon and Wang[14] in reverse mode[4]. All components of the Stokes vector (L, Q, U, V) are modeled. This allows not only a correction for the radiometric calibration parameters M_{11}, but also for the polarization correction parameters m_{12} and m_{13}. The modeled TOA radiances are compared to the radiances measured by MODIS for every scan angle, mirror side, and detector. This means that the instrument characterization parameters (M_{11}, M_{12}, M_{13}) can be derived as a function of scan angle, mirror side, and detector. To reduce noise, the scan angle dependence is modeled by a cubic function for M_{11}, as a linear function for M_{12} and M_{13}.

The retrieval of the instrument characterization parameters is repeated for one day in every month of the mission. This results in a time series for the instrument characterization parameters. The results are smoothed over time using 5th order polynomials before they are applied in the processing of ocean color products.

4. PRELIMINARY RESULTS FOR MODIS AQUA

The results for MODIS Aqua shown in this section are preliminary insofar as that the truth data (SeaWiFS) has recently been reprocessed, and the MODIS Aqua calibration has been modified as well. The results presented here are based on both the old SeaWiFS and old MODIS Aqua calibration. We expect to have updates with the final plots available early 2010.

Fig.1 shows the results for the M_{11} coefficients for bands 8, 10, 12, and 13 (center wavelengths of 412nm, 488nm, 547nm, and 667nm, resp.) as a function of frame (or view angle). It can be seen that the corrections required for band 8 are much larger than for the other bands, especially at the end of the mission. E.g., at the end of the scan, Fig.1 suggests that the TOA radiances of band 8 need to be reduced by almost 3%, whereas they should be increased by 3% around frame 300.

The current plan for the MODIS Aqua reprocessing is to use the corrections for band 8. Whether the corrections for some of the other bands should also be applied will be decided during the evaluation phase of MODIS Aqua reprocessing.

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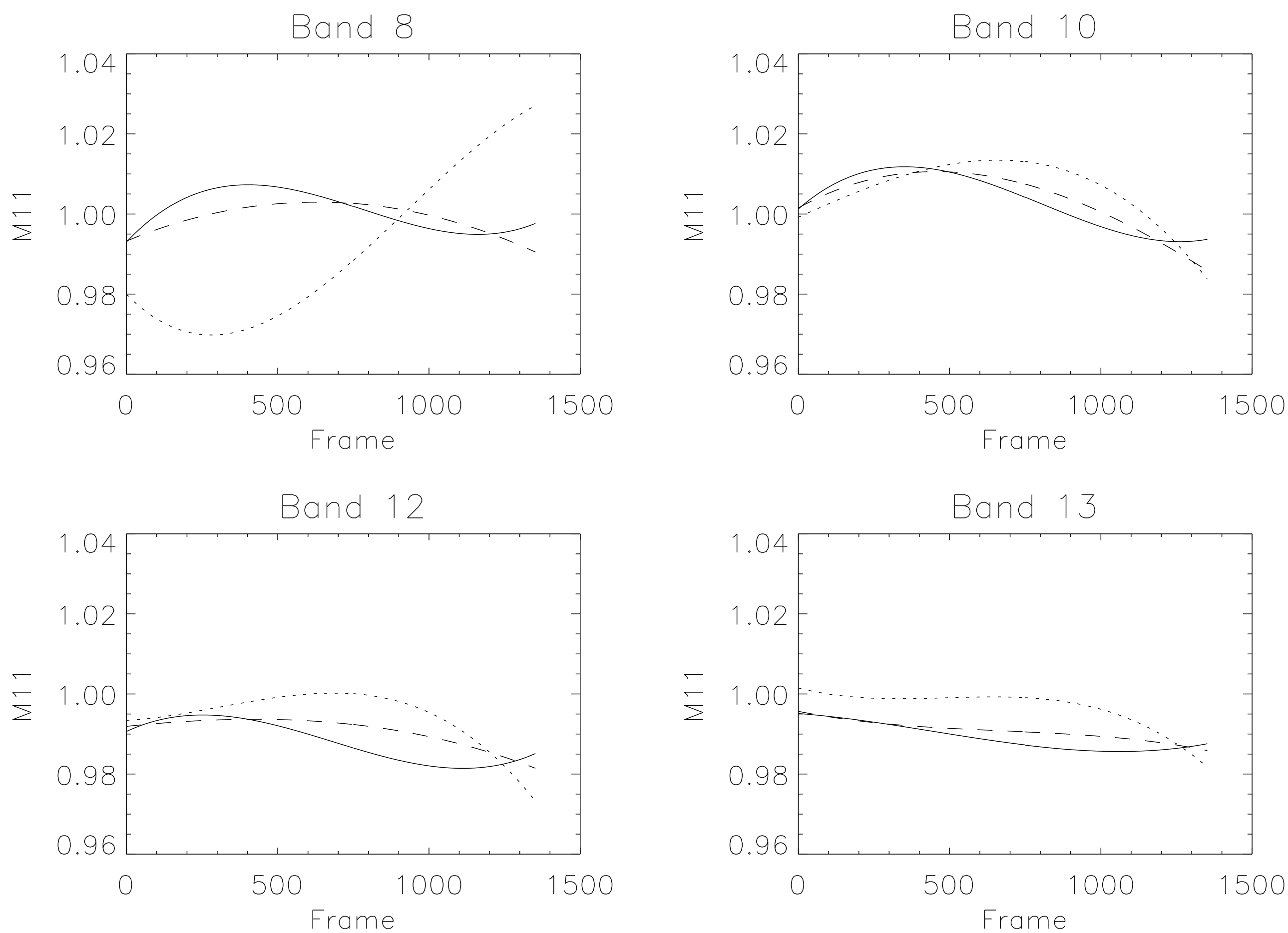

Fig. 1. Correction to the MODIS calibration coefficients for bands 8, 10, 12, and 13, resp., as a function of frame. The frame is proportional to the view angle, frame = 0 corresponds to the beginning of the scan (view angle of $-55°$), frame = 1353 corresponds to the end of the scan (view angle of $+55°$). Solid line is for the beginning of the Aqua mission, dashed line is for the middle, dotted line for the end.

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