The MODIS Aqua Point-Spread Function for Ocean Color Bands

Gerhard Meister[1], Bryan A. Franz[2], Kevin Turpie[2] and Charles R. McClain[3]

[1]Futuretech Corporation, NASA Code 614.2, Goddard Space Flight Center, Greenbelt, Maryland, USA
[2]SAIC, NASA Code 614.2, Goddard Space Flight Center
[3]NASA Code 614.2, Goddard Space Flight Center

Abstract: This paper describes a correction for instrument straylight effects in the MODIS Aqua ocean color bands. The correction is derived from prelaunch characterization measurements, where MODIS scanned across an illuminated slit. The expected straylight effects are demonstrated on artificial images.

1. Introduction

This paper presents recent advances in the stray light correction for the MODIS (Moderate Resolution Imaging Spectroradiometer, see Barnes et al. (1998)) on NASA's EOS (Earth Oberserving Systems) Aqua satellite. The focus of this investigation is on the MODIS ocean color bands (MODIS bands 8-16, corresponding to wavelengths from 412nm to 870nm), which all have a nadir resolution of 1km x 1km. MODIS is a scanning radiometer, with 10 detectors simultaneously recording for the ocean color bands, resulting in a scan line of 10 x 1354 pixels.

A Point-Spread Function (PSF) is required to correct for straylight artifacts that are associated with contamination of the currently viewed pixel by light from outside the nominal FOV (field-of-view) of the current pixel. The PSF is defined as

$$L_m(X_0, Y_0) = \sum_{i,j} PSF(i - X_0, j - Y_0) * L_T(i, j). \quad (1)$$

where $L_m(X_0,Y_0)$ is the measured radiance from pixel (X_0,Y_0), L_T is the true radiance. The summation is supposed to cover all directions from which light enters the sensor, but is in practice limited by the actual size of the image. The PSF is normalized to 1:

$$\sum_{i,j} PSF(i, j) = 1. \quad (2)$$

The first part of this paper (sections 2 and 3) describes the PSF model creation. The second part (section 4) applies the PSF to artificial scenes, showing that even at a distance of 50 pixels from a large cloud, the correction can be significant. The intensity of the correction depends strongly on the size of the cloud and varies from band to band.

2. Prelaunch Characterization

MODIS was characterized by Santa Barbara Remote Sensing (SBRS), California. Line-Spread Functions (LSFs) were acquired along-scan and along-track in two different modes: 1) varying the slit position by fractions of a pixel to determine the Modulation Transfer Function (MTF), and 2) keeping the slit position constant, but inserting neutral density filters and measuring at different light intensities. With the second method, measurements of pixels far away from the slit measured with a high light intensity on the slit (so high that the slit measurements actually saturate) can be merged with measurements where the slit does not saturate. This type of LSF is called Near-Field Response (NFR) by SBRS, see Hurt and Derrick (2000). The dynamic range of the MTF measurements is about $1\text{-}10^{-3}$, for the NFR measurements it is about $1\text{-}10^{-7}$. In order to characterize the system response to a bright target several pixels away from the bright target, NFR measurements are needed. MODIS NFR was only characterized in the along-scan direction, not in the along-track direction. MODIS MTF was characterized for both directions.

The MODIS Aqua NFR measurements are described by Harvey-Shack functions in Derrick (2002). The model was created for MODIS by Young (1995). It predicts the measured response for pixels further than 1 pixel away from the slit. The model either uses one or a combination of two Harvey-Shack functions, depending on whether the light was scattered outside or inside of the MODIS field baffle. The NFR measurements are only available for detector 5.

3. Derivation of the PSF

The general shape of the PSF is given by the Harvey-Shack based model from SBRS. The along-track scattering is assumed to be identical to the along-scan scattering. The crucial issue for the creation of the PSF is the normalization of the SBRS model relative to the center pixel. The approach chosen here is to estimate the PSF of the central 3x3 pixels based on 1) the LSFs in the along-track direction measured for the MTF characterization (see e.g. Barnes et al. (1998), Fig. 3a) and 2) the theoretical value for the adjacent pixel in scan direction from Nishihama et al. (1997). The results are given as a function of the value of the PSF (p_0) of the central pixel (X_0, Y_0) in Table 1.

Table1. Modeled PSF of the central 3 pixels

Scan index	Track index	Value
X_0	Y_0	p_0
X_0+/-1	Y_0	0.125/0.75*p_0
X_0	Y_0+/-1	0.05*p_0
X_0+/-1	Y_0+/-1	0.125/0.75*0.05*p_0

The normalization constant for the Harvey-Shack model and p0 are then optimized so that the resulting PSF reproduces the NFR measurements. The sum of the PSF of the central 3x3 pixels for MODIS Aqua band 11 is 0.9971. For MODIS Terra, Qiu et al. (2000) reported a value of 0.9932 for band 11, i.e. significantly more scatter than we find in MODIS Aqua. The agreement between modeled and measured NFR is shown in Fig. 1 for band 11, the modeled PSF is shown in Fig. 2. All 10 detectors are assumed to have the same Harvey-Shack coefficients as detector 5, but their PSFs are different due to their different position on the focal plane relative to the MODIS field baffle.

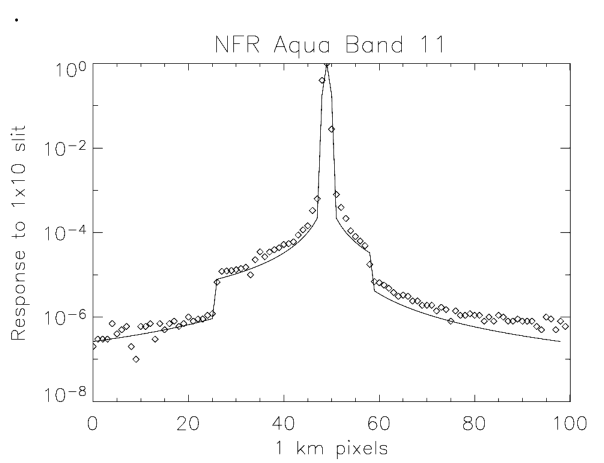

Figure 1. NFR measurements (diamonds) and NFR modeled from PSF (solid line) for MODIS Aqua band 11.

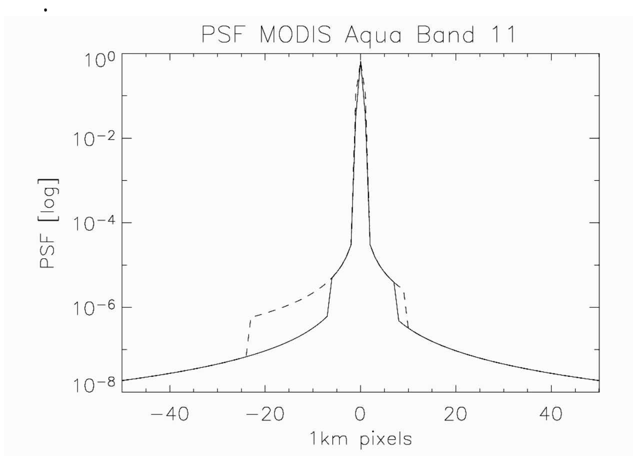

Figure 2. MODIS Aqua Band 11 PSF in track direction (solid line) and scan direction (dashed line).

The equivalent of Fig.1 has been shown in Qiu et al. (2000) for MODIS Terra. Qualitatively, the NFR measurements of both MODIS instruments are similar, but the MODIS Aqua NFR measurements are generally lower, i.e. there is more stray light in MODIS Terra.

The measured NFR values in Fig.1 are slightly higher than the modeled values after the peak (right side of Fig.1). Generally, data measured after the peak are less reliable and were not used in the fitting of the Harvey-Shack parameters by Derrick (2002).

The equivalent of Fig.2 is shown in Qiu et al. (2000) for MODIS Terra. 30 pixels away from the center peak, the PSF of MODIS Terra is a little less than 10^{-6}, whereas for MODIS Aqua it is $4.5x10^{-8}$. Unfortunately, the PSF model used in Qiu et al. (2000) is unavailable, the publication is the only source of information we can use.

4. Application to test images

Following the method outlined in Qiu et al. (2000), an artificial image with 512x512 pixel was created with the left (or right) half of the image containing cloud radiances (L_{cloud}), the other half typical radiances (L_{typ}; a ratio L_{cloud}/L_{typ} of exactly 20 was chosen in Fig.3 to ensure comparability to data in Qiu et al.). Qiu did not define if the cloud is at the beginning of the scan (BOS) or end of scan (EOS), so we calculated both cases. The PSF was applied to the artificial image to simulate the scattering of MODIS Aqua. The radiance error is the difference of the simulated image with scatter and the artificial input image. The results are shown in Fig.3 as a function of the distance to the cloud. The values for MODIS Terra were read from the figure in Qiu et al., and are therefore only approximate. It can be seen that the contamination of MODIS Aqua band 11 top-of-atmosphere radiances due to a large cloud is significant (1% contamination 8km or 13km away from the cloud, for the cloud being at the beginning or end of scan, respectively), but the contamination is much less than for MODIS Terra (1% contamination 21 pixels away from the cloud).

The cloud used in Fig.3 is very large. The effect from a much smaller cloud (only 10x10 pixels) can be seen in Fig.4 for MODIS Aqua bands 8, 11, 13, and 16, using ratios L_{cloud}/L_{typ} of 12.8, 19.3, 49.6, and 46.1. (values as defined in the MODIS specifications). E.g. 10 pixels away from the cloud, the contamination is 0.225% for band 11. The strong variation between the bands is partly due to the different L_{cloud}/L_{typ} ratios, partly due to different PSFs, see strong variation in the sum of the PSF of the central 3x3 pixels shown in Fig.5. The between band variation is problematic for the ocean color products, because often stray light is removed from the ocean color products because it is (erroneously) characterized as aerosol contribution; the quality of the derived products suffers if the stray light contribution is wavelength dependent.

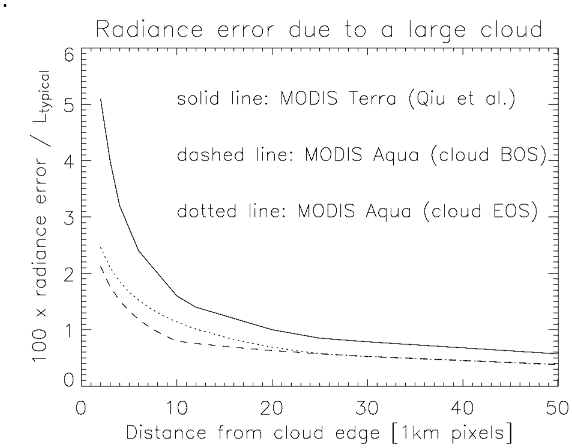

Figure 4. Contamination of top-of-atmosphere radiances over ocean due to a large cloud (semi-infinite) for MODIS Aqua band 11.

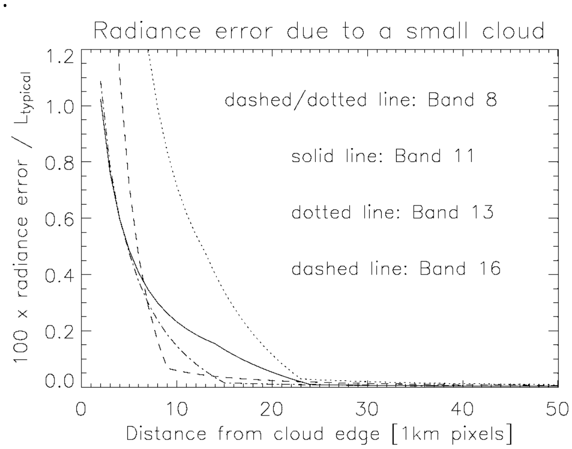

Figure 3. Contamination of top-of-atmosphere radiances over ocean due to a small cloud (10x10 pixels).

5. Outlook

The results presented here are preliminary and require further testing. We are planning to apply the correction to real MODIS data to quantify the effect of stray light on the retrieval of chlorophyll, water-leaving radiance, and AOT (aerosol optical thickness). Currently, a 5x7 mask is applied around cloud pixels, which has significantly improved the agreement between the AOT of MODIS Aqua and the SeaWiFS sensor, see Bryan et al. (2005).

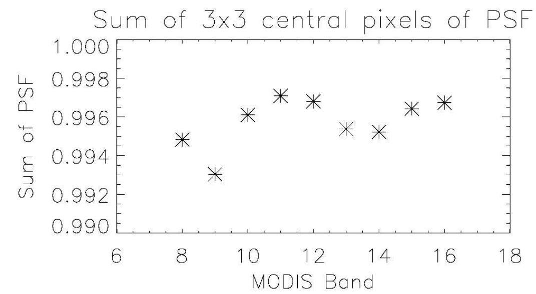

Figure 5. Sum of the central pixels of the PSF for bands 8-16.

Acknowledgment

Roger Drake from SBRS/Raytheon provided the prelaunch characterization data.

References

[1] Barnes, W., T. S. Pagano and V. V. Salomonson (1998). Prelaunch characteristics of the Moderate Resolution Imaging Spectroradiometer (MODIS) on EOS-AM1, IEEE Transactions on Geoscience and Remote Sensing, vol.36, pp. 1088-1100.

[2] Bryan, F. A., et al. (2005). The continuity of ocean color measurements from SeaWiFS to MODIS, SPIE vol. 5882, in press.

[3] Derrick, P. (2002). MODIS FM1 Harvey-Shack Scattering Model Analysis, Raytheon, Interdepartmental Correspondence, Ref PL3095-N07881.

[4] Hurt, T., and P. Derrick (2000). MODIS FM1 Near Field Response, Raytheon, Interdepartmental Correspondence, Ref PL3095-N07729 Rev A.

[5] Nishihama, M., et al. (1997). MODIS Level 1A Earth Location: Algorithm Theoretical Basis Document, version 3.0, , section 2.3.1.1, NASA Goddard Space Flight Center.

[6] Qiu,, S., G. Godden, X. Wang, and B. Guenther (2000). Satellite-Earth remote sensor scatter effects on Earth scene radiometric accuracy. Metrologia, vol. 37, pp. 411-414.

[7] Young, J.B. (1995). Point Spread Function (PSR) near field response measurements methodology – revision, Ref PL3095-N05401, SBRC internal memorandum.

Address:

Gerhard Meister, Futuretech Corporation, NASA Code 614.8, Goddard Space Flight Center, Greenbelt, MD 20771, USA. (meister@simbios.gsfc.nasa.gov)