Four Years of Aqua MODIS On-orbit Radiometric Calibration

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ABSTRACT

MODIS is currently onboard NASA's EOS Terra and Aqua spacecraft launched in December 1999 and May 2002, respectively. Together, Terra and Aqua MODIS have generated over 10 years of global observations for the study of changes in the Earth's land, oceans, and atmosphere. Each sensor produces more than 40 science data products using measurements from 36 spectral bands with wavelengths ranging from 0.41 to 14.4μm. MODIS on-orbit radiometric calibration is performed using a solar diffuser (SD) and a solar diffuser stability monitor (SDSM) for the reflective solar bands (RSB) and a blackbody (BB) for the thermal emissive bands (TEB). In addition, regularly scheduled lunar observations are used to track RSB radiometric calibration stability. This paper discusses Aqua MODIS radiometric calibration performance using four-years of on-orbit calibration data. Results include detector noise characterization (SNR for the RSB and NEdT for the TEB), short- and long-term radiometric stability, and optics (scan mirror and solar diffuser) degradation.

Keywords: Aqua, MODIS, sensor, radiometric calibration, solar diffuser, blackbody

1. INTRODUCTION

The first Moderate Resolution Imaging Spectroradiometer (MODIS) was launched onboard the NASA Earth Observing System (EOS) Terra spacecraft on December 18, 1999 and the second was launched onboard the Aqua spacecraft on May 4, 2002. The Terra MODIS is in a 705km sun-synchronous ascending near-polar orbit with an equatorial crossing time of 1:30 p.m. local time while the Aqua MODIS in a descending orbit with an equatorial crossing time of 10:30 a.m. local time. As a major contribution to the NASA EOS missions, there are more than 40 science products continuously generated from both Terra and Aqua MODIS observations and widely distributed for the study of changes in the Earth's land, oceans, and atmosphere[1-4].

The MODIS has 36 spectral bands, covering a spectral wavelength range from 0.41 to 14.4μm. The 36 bands include 20 reflected solar bands (RSB) and 16 thermal emissive bands (TEB). Observations are made at three different nadir resolutions: 250m (2 bands), 500m (5 bands) and 1km (29 bands). The MODIS uses a two-sided paddle-wheel scan mirror that scans ±55^o off nadir for the Earth view (EV) data collection, corresponding to a swath of 2330km cross track by 10km along-track. The 36 MODIS bands are located on four focal plan assemblies (FPA): the visible (VIS), near-infrared (NIR), short- and mid-wave infrared (SMIR) and long-wave infrared (LWIR). The VIS and NIR FPA are kept at instrument ambient temperatures, while the SMIR and LWIR FPA are maintained at 83K. The detector arrays consist of 40, 20, or 10 detectors (aligned along-track) that cover the cross-track sampling at the three different spatial resolutions. MODIS on-orbit radiometric calibration is primarily conducted using a blackbody (BB), a solar diffuser (SD), a solar diffuser stability monitor (SDSM), a spectro-radiometric calibration assembly (SRCA), and a space view (SV) port. The BB is a V-grooved design blackbody with a controlled temperature for scan-by-scan determination of the TEB linear calibration coefficient (b_1). The BB temperature can be adjusted over a wide range to determine the intercept (a_0) and quadratic (a_2) terms used for the TEB calibration. The calibration of the RSB depends on measurements made by the SD and SDSM and periodic lunar observations obtained from the SV port. Measurements from the SD and SDSM are used for absolute calibration, while lunar observations are used to track on-orbit response changes at different angles-of-incidence (AOI). The SRCA was designed primarily to track instrument on-orbit spatial (RSB and TEB) and spectral (RSB) performance[5-11].

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In this paper, an overview of the four-year Aqua MODIS on-orbit radiometric calibration and characterization performance is presented. It is an update to several previous studies based on early Aqua MODIS on-orbit results[12-15]. The following TEB and RSB calibration sections briefly describe the calibration algorithms, followed by the results from on-orbit observations that demonstrate the sensor's overall performance and calibration quality.

2. AQUA MODIS TEB ON-ORBIT CALIBRATION AND PERFORMANCE

MODIS TEB calibration is provided by a set of spectral band, detector, and mirror side dependent coefficients a_0, b_1 and a_2 that determine the observed EV radiance, L_{EV}, using a quadratic algorithm,

$$RVS_{EV} \cdot L_{EV} + (RVS_{SV} - RVS_{EV}) \cdot L_{SM} = a_0 + b_1 \cdot dn_{EV} + a_2 \cdot dn_{EV}^2 \quad (1)$$

where dn_{EV} is detector EV response, RVS_{SV} and RVS_{EV} are the relative response versus scan angle (RVS) at SV and EV AOI, and L_{SM} is the scan mirror thermal emission. Coefficients a_0 and a_2 were derived during pre-launch calibration and characterization and updated on-orbit as necessary using measurements from quarterly scheduled BB warm-up and cool-down cycles. Values of b_1 are provided on a scan-by-scan basis from detector response to the BB,

$$\begin{aligned} &RVS_{BB} \cdot \varepsilon_{BB} \cdot L_{BB} + (RVS_{SV} - RVS_{BB}) \cdot L_{SM} + RVS_{BB} \cdot (1 - \varepsilon_{BB}) \cdot \varepsilon_{CAV} \cdot L_{CAV} \\ &= a_0 + b_1 \cdot dn_{BB} + a_2 \cdot dn_{BB}^2 \end{aligned} \quad (2)$$

The first term on the left hand side (LHS) is the source term from the BB, the second term is due to scan mirror thermal emission, and the third term is the contribution from instrument scan cavity. L_{BB}, L_{SM}, and L_{CAV} are computed using Planck's equation using BB, scam mirror, and scan cavity temperatures and detectors' relative spectral response (RSR). Changes in instrument electronic configuration or aging of the instrument may require a re-set of a_0 and a_2.

The stability of linear calibration coefficient b_1 is a key indicator for the TEB overall system level performance. Figure 1 shows Aqua MODIS LWIR band 31 (all 10 detectors or channels) scan-by-scan b_1 from measurements made in one complete orbit (about 100 min or 2000 scans). The small (less than 0.5%) peak-to-peak variations of b_1 during each orbit are primarily due to the variations of LWIR FPA temperatures as shown in Figure 2. As illustrated in Figure 3, the BB temperatures, averaged over measurements from 12 thermistors, have been extremely stable with variations of less than 10mK. The dashed lines correspond to transitions from nighttime to daytime (first) and from daytime to nighttime (second).

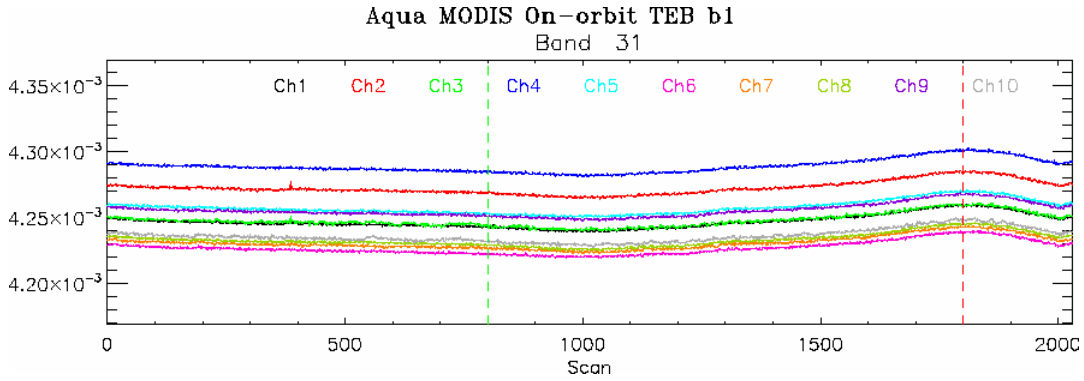

Figure 1: Aqua MODIS band 31 detectors' scan-by-scan response (b_1 in units of W/m^2/sr/μm per digital count) from mirror side 1 in one orbit (0:00 to 1:35 GMT, June 29, 2006).

4. SUMMARY

Aqua MODIS has been operating normally since its launch in May 2002. In this paper, the performance of Aqua MODIS radiometric calibration over its four-year mission has been summarized and examples of instrument on-orbit characterization are presented. For the thermal emissive bands, detectors' noise characterization has been extremely stable. For the reflective solar bands, a slight drop in SNR is observed for band 8, 9, and 10 due to the optical degradations of these bands. Other than that, the short/long-term responses from all the functional detectors have been very stable. The time-dependent slow changes of sensor responses have been tracked and corrected in the calibration. Overall performance of Aqua MODIS is generally better than Terra MODIS. The two MODIS sensors have enabled the development of many climate and environmental parameters for comprehensive studies and better understanding of the Earth as a system.