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MODIS on-orbit calibration and characterization

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Abstract
The MODIS Protoflight Model, launched on-board the NASA EOS Terra spacecraft on 18 December 1999, has been in operation for more than two years, providing the science community with calibrated data sets for global studies of the Earth's land, oceans and atmosphere. MODIS has 36 spectral bands, covering the spectral range from 412 nm to 14 200 nm, and provides spatial resolutions of 0.25 km (two bands), 0.5 km (five bands) and 1 km (29 bands) at nadir. The key on-board calibrators (OBCs) include a solar diffuser (SD) and a solar diffuser stability monitor (SDSM) system for calibration of the reflective solar bands, and a V-grooved flat-panel blackbody (BB) for calibration of the thermal emissive bands. In this paper, we describe the use of OBCs for the sensor's radiometric calibration and characterization and discuss on-orbit performance. In addition, we provide an assessment of the on-orbit degradation of the SD and MODIS optics.

1. Introduction

The MODerate Resolution Imaging Spectroradiometer (MODIS) Protoflight Model (PFM) is the key instrument on the NASA Earth Observing System (EOS) Terra spacecraft. The instrument was designed to provide the science community with improved observations relative to 'heritage sensors' for long-term global studies of the land, oceans and atmosphere. Terra was launched on 18 December 1999 in a near sun-synchronous polar orbit (orbit altitude = 705 km) descending southward with a nadir equator crossing time of 10:30 am. Using a two-sided scan mirror, the MODIS 1 km bands sample the Earth scenes 1354 times every 1.478 s. The $\pm 55^{\circ}$ degree scan (relative to nadir) produces a swath of 10 km (at nadir) along track and 2330 km crosstrack. For the 0.5 km and 0.25 km resolution bands, there are two sub-samples and four sub-samples respectively, corresponding to each 1 km resolution sample. For over two years, Terra MODIS has been performing well on-orbit.

This paper provides a brief overview of the instrument and describes the MODIS on-orbit calibration and characterization through the use of its on-board calibrators (OBCs). It focuses on the applications of the solar diffuser (SD) and solar diffuser stability monitor (SDSM) system for radiometric calibration of the sensor's reflective solar bands and the blackbody (BB) for radiometric calibration of its thermal emissive bands. Results are presented of any changes or trends in the system response and detector noise characterization, derived from on-orbit observations.

2. Instrument background

MODIS has 36 spectral bands with wavelengths ranging from 412 nm to 14 200 nm. It provides spatial resolutions of 0.25 km (two bands with 40 along-track detectors each), 0.5 km (five bands with 20 along-track detectors each) and 1 km (29 bands with ten along-track detectors each) at nadir. The 36 spectral bands are distributed on four focal plane assemblies (FPAs): VIS, NIR, SW/MWIR and LWIR. Two of the 1 km resolution bands (bands 13 and 14 at 667 nm and 678 nm), using two rows of detectors in time delay and integration (TDI), provide measurements of the same scene at both low gain and high gain.

MODIS OBCs include an SD/SDSM system for radiometric calibration of the reflective solar bands (RSB), a

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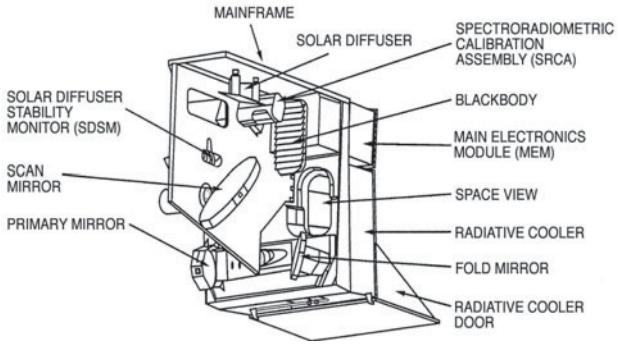

Figure 1. MODIS scan cavity and on-board calibrators.

BB for radiometric calibration of the thermal emissive bands (TEB), and a spectroradiometric calibration assembly (SRCA) for the sensor's spatial and spectral calibration. Figure 1 shows the instrument scan cavity and the on-board calibrators. The sensor views cold space through the space view port to observe the dark response and thermal background of the system.

Pre-launch, the instrument completed various sub-system and system level tests. Key radiometric calibrations in the thermal vacuum included the TEB calibration using an external high emissivity blackbody calibration source (BCS) operated from 170 K to 340 K and the RSB calibration using a spectral integration sphere (SIS) operated with a series of lamp levels to provide the necessary dynamic range. In addition, the sensor's response and noise characterization were studied at different instrument temperatures and, for the TEB, at different cold FPA temperatures. A detailed description of the MODIS instrument characterization and pre-launch calibration results has been provided by Barnes *et al* [1].

3. On-orbit calibration and characterization

The MODIS Level 1B algorithm converts instrument digital numbers into geolocated and radiometrically calibrated products. This data is then used for developing a broad range of science products. MODIS L1B primary products are reflectance factors for the RSB and top of the atmosphere (TOA) radiances for the TEB. The RSB (bands 1–19, 26) on-orbit calibration is implemented in the L1B through the use of a series of look-up tables (LUTs) filled with calibration coefficients derived from frequently scheduled SD calibrations (weekly during the first two years and biweekly thereafter). The TEB (bands 20–25, 27–36) on-orbit calibration is performed in the L1B using the scan-by-scan OBC BB observations.

3.1. Solar diffuser and RSB calibration

The solar diffuser was made of Spectralon materials. Its bi-directional reflectance factor (BRF) from 400 nm to 1700 nm was characterized pre-launch using a scattering goniometer and a known BRF standard reference sample traceable to NIST. On-orbit, the solar diffuser frequently views the sun and provides updates for the RSB calibration parameters. For a given band, detector, sub-frame (for sub-km bands) and mirror side, the Earth view reflectance factor, $\rho_{\mathrm{EV}}\cos(\theta_{\mathrm{EV}})$, can be expressed as [2]

$$\rho_{\mathrm{EV}}\cos(\theta_{\mathrm{EV}}) = m_1\, dn_{\mathrm{EV}}\, d^2_{\mathrm{ES(EV)}} \tag{1}$$

where m_1 is a reflectance scaling factor, dn_{EV} is the Earth view 'corrected' digital number (corrected for instrument background, temperature variation and scan angle response) and $d_{\mathrm{ES(EV)}}$ is the Earth–Sun distance at the time of the Earth view observation. Similarly, the scaling factor is computed from SD observations using SD BRF with its on-orbit degradation (Δ_{SD}) corrected,

$$m_1 = \frac{\mathrm{BRF}\cos(\theta_{\mathrm{SD}})}{dn_{\mathrm{SD}}\, d^2_{\mathrm{ES(SD)}}}\Delta_{\mathrm{SD}}\Gamma \tag{2}$$

where Γ is the vignetting function for bands that use the SD attenuation screen during calibration, $d_{\mathrm{ES(SD)}}$ is the Earth–Sun distance during the SD calibration and dn_{SD} is solar diffuser corrected digital number. The distance correction is needed in both (1) and (2) since the SD calibration and the Earth views are not performed at the same time. For the bands that do not use the SD screen, Γ is set to 1. The SD on-orbit degradation (Δ_{SD}) is determined from the solar diffuser stability monitor. The SDSM consists of a solar integrating sphere with nine filtered detectors monitoring wavelengths ranging from 410 nm to 940 nm. It works as a ratioing radiometer, viewing the sun through an attenuation screen and the light diffusely reflected from the SD alternately during calibration, and thus tracks the SD's on-orbit degradation [3].

3.2. BB and TEB calibration

MODIS TEB on-orbit calibration is performed using a full aperture V-grooved flat panel BB with 12 thermal sensors embedded in the BB substrate. The pre-launch characterization of the OBC BB was achieved using an external high emissivity BCS, referenced to NIST temperature standards. On-orbit, the OBC BB is capable of operating in a temperature range from 270 K to 315 K. TEBs use a quadratic algorithm in the calibration. BB warm-up and cool-down data are used to derive the detectors' offset (a_0) and non-linear (a_2) terms on-orbit. The first-order coefficient (b_1) is determined scan-by-scan from OBC BB observations, except for B21 (a low-gain band for fire detection) that uses fixed-gain coefficients due to the limited dynamic range from the OBC BB temperature.

5. Summary

MODIS on-board calibrators have been used for the sensor's on-orbit calibration and characterization. The SD degradation and optics degradation effects, including the AOI-dependent response, are included in the calibration algorithms. For over two years, Terra MODIS has been performing well and is continuing to provide calibrated data sets for a broad user community. MODIS level 1B products and other science products are made freely available to the public through NASA Goddard Earth Science (GES) Distributed Active Archive Center (DAAC: http://daac.gsfc.nasa.gov/).