Terra MODIS On-Orbit Spectral Characterization and Performance

X. Xiong, N. Che, and W. L. Barnes

***Abstract*—The Moderate Resolution Imaging Spectroradiometer (MODIS) protoflight model onboard the National Aeronautics and Space Administration's Earth Observing System Terra spacecraft has been in operation for over five years since its launch in December 1999. It makes measurements using 36 spectral bands with wavelengths from 0.41 to 14.5 μm. Bands 1–19 and 26 with wavelengths below 2.2 μm, the reflective solar bands (RSBs), collect daytime reflected solar radiance at three nadir spatial resolutions: 0.25 km (bands 1–2), 0.5 km (bands 3–7), and 1 km (bands 8–19 and 26). Bands 20–25 and 27–36, the thermal emissive bands, collect both daytime and nighttime thermal emissions, at 1-km nadir spatial resolution. The MODIS spectral characterization was performed prelaunch at the system level. One of the MODIS onboard calibrators, the Spectroradiometric Calibration Assembly (SRCA), was designed to perform on-orbit spectral characterization of the MODIS RSB. This paper provides a brief overview of MODIS prelaunch spectral characterization, but focuses primarily on the algorithms and results of using the SRCA for on-orbit spectral characterization. Discussions are provided on the RSB center wavelength measurements and their relative spectral response retrievals, comparisons of on-orbit results with those from prelaunch measurements, and the dependence of center wavelength shifts on instrument temperature. For Terra MODIS, the center wavelength shifts over the past five years are less than 0.5 nm for most RSBs, indicating excellent stability of the instrument's spectral characteristics. Similar spectral performance has also been obtained from the Aqua MODIS (launched in May 2002) SRCA measurements.**

***Index Terms*—Calibration, instrument, remote sensing.**

I. Introduction

THE MODERATE Resolution Imaging Spectroradiometer (MODIS) is one of the major instruments for the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) missions. The MODIS protoflight model (PFM) onboard the EOS Terra spacecraft has been in operation for over five years since its launch in December 1999. Flight model 1 (FM1) onboard the EOS Aqua spacecraft, launched in May 2002, has been in operation for more than three years. MODIS was designed with the capability to extend and enhance a number of heritage sensors' observations and data records for studies of the Earth system and its land, oceans, and atmosphere [1]–[4]. There are approximately 40 science data products that are routinely produced from MODIS observations, including land/cloud boundaries and properties, ocean color, sea-surface temperature, and atmospheric water vapor.

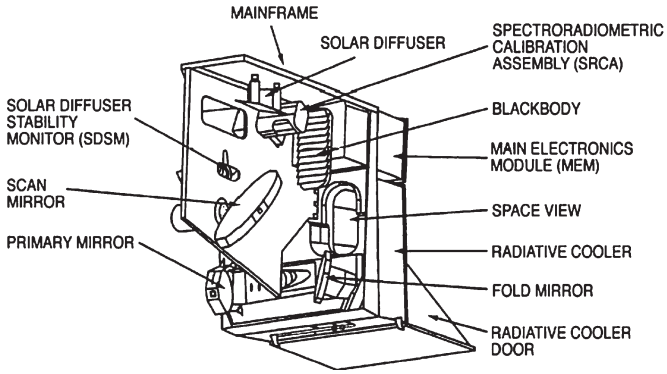

Fig. 1. MODIS scan cavity and OBCs.

Each MODIS instrument makes observations using 36 spectral bands with wavelengths ranging from 0.41 to 14.5 μm at three spatial resolutions (nadir): 0.25 km (bands 1–2), 0.5 km (bands 3–7), and 1 km (bands 8–36). The number of detectors per spectral band is 40, 20, and 10 for the 0.25-, 0.5-, and 1-km spatial resolution bands, respectively. The detectors for the 36 spectral bands are located on four focal plane assemblies (FPAs) according to their wavelengths: visible (VIS), near-infrared (NIR), short- and midwave infrared (SWIR/MWIR), and longwave infrared (LWIR). The VIS and NIR are uncooled FPAs while the SWIR/MWIR and LWIR FPAs are controlled nominally at 83 K. MODIS bands 1–19 and 26 with wavelengths from 0.41 to 2.2 μm are the reflective solar bands (RSBs), and the other 16 bands with wavelengths from 3.5 to 14.5 μm are the thermal emissive bands (TEBs). MODIS is a cross-track scanning radiometer that makes measurements using a two-sided scan mirror. It is equipped with a set of onboard calibrators (OBCs) for its on-orbit calibration and characterization. Fig. 1 shows the MODIS scan cavity and the locations of the OBCs. For radiometric calibration purposes, a solar diffuser (SD) and a SD stability monitor (SDSM) are used together for the RSB and a blackbody for the TEB [5]–[7]. The Spectroradiometric Calibration Assembly (SRCA) is primarily used for the instrument spatial and spectral characterization [8]–[11]. This paper presents MODIS spectral characterization approaches and results for the Terra MODIS RSBs.

Typically, spectral characterization of the instrument is performed prelaunch. The characterization includes measurements of each spectral band's center wavelength, bandwidth (BW), and relative spectral response (RSR). Often the RSR measurements include characterization of the band's out-of-band

Manuscript received May 16, 2005; revised November 29, 2005.

X. Xiong is with the Earth Sciences Directorate, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: xioaxiong.xiong.1@gsfc.nasa.gov).

N. Che is with Science Systems and Applications, Inc., Lanham, MD 20706 USA (e-mail: nianzeng_che@ssaihq.com).

W. L. Barnes is with the University of Maryland Baltimore Country, Baltimore, MD 21250 USA (e-mail: wbarnes@neptune.gsfc.nasa.gov).

Digital Object Identifier 10.1109/TGRS.2006.872083

(OOB) response. For a number of reasons, the sensors' spectral characteristics could change from prelaunch to on orbit. The difference between the ground test environment and space and launch-related effects may introduce changes in instrument response. Environmental temperature variations often cause spectral response changes due to changes in the coating-film thicknesses and thus the associated reflectance or transmittance. Degradation of the optics over time during in-flight operation could also impact the sensor's spectral characteristics. Tests have shown that spectral filters of the multilayer thin-film type can experience significant spectral response shifts [12]. Therefore, it is important to track the spectral characteristics throughout the sensor's lifetime in order to assure accurate evaluation of its effect on instrument performance and to enable accurate radiometric calibration.

On-orbit spectral calibration is often utilized with hyperspectral sensors. In the Hyperion hyperspectral imager onboard the NASA EO-1 satellite, spectral calibration is performed using the spectral features of a doped spectralon panel [13]. Measuring the reflected solar beam from the Hyperion cover and comparing it with solar and atmospheric absorption lines validates the spectral calibration. The spectral calibration for the Environmental Satellite (ENVISAT) uses an internal spectral line source and the calibration results are compared to solar Fraunhofer lines and atmospheric absorption features [14]. The atmospheric chemistry experiment (ACE) uses the absorption lines of the solar spectrum for its on-orbit spectral calibration. In addition, a laser diode is used as a spectral source. The wavelength shift of the diode is corrected for instrument temperature and current changes [15]. The response due to solar Fraunhofer lines is utilized for wavelength calibration of the limb-viewing broadband imaging spectrometer of the ozone mapping and profiler suite (OMPS) [16]. The spectral calibration of the atmospheric infrared sounder (AIRS) compares upwelling radiance spectra against precalculated radiance spectra. For verification purposes, the observed radiance spectra of the onboard spectral calibrator (a Parylene coating with spectral features) are also compared against precalculated radiance spectra [17].

The common feature of these hyperspectral instruments is that their BWs are very narrow and their spectral response depends on detector array location. For broadband multispectral instruments, accurately tracking spectral response is a challenge. For this purpose, the MODIS is equipped with a unique device that is capable of performing on-orbit spectral characterization of its RSBs (VIS, NIR, and SWIR bands). This appears to be the first such device for a remote-sensing multispectral instrument.

We present in this paper a brief overview of MODIS prelaunch spectral characterization and describe the spectral calibration transfer from ground measurements to the OBC (SRCA). We discuss the SRCA spectral characterization algorithms and on-orbit results for the MODIS RSB, including center wavelengths, RSR, and dependence of center wavelength shifts on the instrument's temperature. For Terra MODIS, the center wavelength shifts on orbit, over the past five years, are less than 0.5 nm for most RSBs, indicating excellent stability of the instrument's spectral characteristics. Examples of Terra MODIS on-orbit spectral characterization results are provided and discussed.

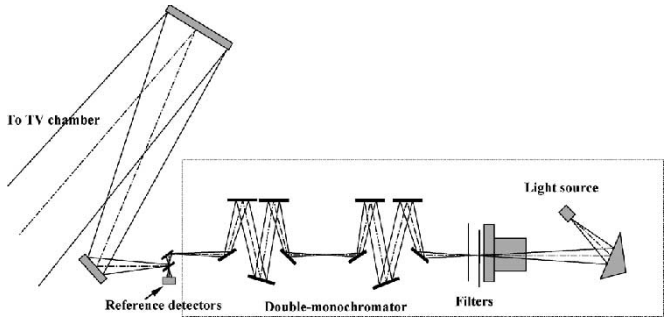

Fig. 2. Schematic of the SpMA.

II. Prelaunch Spectral Characterization

The MODIS prelaunch spectral characterization was made using a spectral measurement assembly (SpMA) in both ambient and thermal vacuum (TV) environments at the instrument vendor, Santa Barbara Remote Sensing (SBRS), Goleta, CA. The SpMA is essentially a double monochromator, as illustrated in Fig. 2. The source box of the SpMA holds gas emission-line sources for internal wavelength calibration. The combination of a lamp and glow bar serves as an illumination source that covers the spectral wavelength range of the MODIS bands. The beam, after passing through the selected diffraction order-sorting filter, is focused onto the entrance slit. The slit width is adjustable depending on the required spectral resolution and signal-to-noise ratio (SNR). Several gratings are utilized to cover the MODIS spectral range from visible to longwave infrared. Located in the optical path, just outside of the double monochromator, are reference detectors [a silicon photodiode (SiPD) and a pyroelectric detector] with known spectral responses that are used to monitor the monochromator's output and to correct for the source spectrum impact on the RSR measurements. The beam from the SpMA's double monochromator is then collimated and folded by a set of mirrors to fill the MODIS aperture. The SpMA output has nearly the same solid angle and area product as that from the Earth scene so that the spectral characterization can be properly measured.

VI. Conclusion

This paper provides a brief description of the MODIS spectral characterization performed prelaunch using the ground-based SpMA and the onboard SRCA and comparisons of the CW and the RSR for both the Terra and Aqua MODIS spectral bands with wavelengths less than 2.2 μm. Observations from over five years of on-orbit operation show that the SRCA has been functioning with good stability and measurement repeatability. The Terra MODIS CWs have shifted since prelaunch characterization, slightly toward shorter wavelengths during the first 1.5 years of on-orbit operation, for most of the bands, and have remained relatively stable since. Except for band 8, the CW shifts for all the Terra MODIS VIS/NIR bands are less than 0.5 nm. If the initial changes from prelaunch to shortly after launch are ignored, the on-orbit shifts over the last five years have been within 0.2 nm on average. It seems that the use of IAD technology stabilizes the band CWs. The lessons learned from the MODIS on-orbit spectral characterization have not only benefited the MODIS science communities, but continue to provide valuable information for the design of future remote sensing instruments.