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An Overview of MODIS Radiometric Calibration and Characterization

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ABSTRACT

The Moderate Resolution Imaging Spectroradiometer (MODIS) is one of the key instruments for NASA's Earth Observing System (EOS), currently operating on both the Terra and Aqua satellites. The MODIS is a major advance over the previous generation of sensors in terms of its spectral, spatial, and temporal resolutions. It has 36 spectral bands: 20 reflective solar bands (RSB) with center wavelengths from 0.41 to 2.1 μm and 16 thermal emissive bands (TEB) with center wavelengths from 3.7 to 14.4 μm, making observations at three spatial resolutions: 250 m (bands 1–2), 500 m (bands 3–7), and 1km (bands 8-36). MODIS is a cross-track scanning radiometer with a wide field-of-view, providing a complete global coverage of the Earth in less than 2 days. Both Terra and Aqua MODIS went through extensive pre-launch calibration and characterization at various levels. In orbit, the calibration and characterization tasks are performed using its on-board calibrators (OBCs) that include a solar diffuser (SD) and a solar diffuser stability monitor (SDSM), a v-grooved flat panel blackbody (BB), and a spectro-radiometric calibration assembly (SRCA). In this paper, we present an overview of MODIS calibration and characterization activities, methodologies, and lessons learned from pre-launch characterization and in-orbit operation. Key issues discussed in this paper include in-orbit efforts of monitoring the noise characteristics of the detectors, tracking the solar diffuser and optics degradations, and updating the sensor's response versus scan angle. The experiences and lessons learned through MODIS have played and will continue to play major roles in the design and characterization of future sensors.

Key words: EOS, remote sensing, Terra, Aqua MODIS, sensor, calibration, radiometry

1. Introduction

The Earth Observing System (EOS) is the centerpiece of NASA's Earth Science Enterprise (ESE). Its overall goal is to enhance the scientific understanding of the Earth's land, oceans, and atmosphere, and the natural and human-induced effects on the global environment and climate changes. The Terra and Aqua spacecraft, launched in December 1999 and May 2002, respectively, are two of the major contributors to the EOS.

The Terra spacecraft carries five Earth observing instruments: (1) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), (2) Clouds and the Earth's Radiant Energy System (CERES), (3) Moderate Resolution Imaging Spectroradiometer (MODIS), (4) Multi-angle Imaging Spectro-Radiometer (MISR), and (5) Measurements of Pollution in the Troposphere (MOPITT). Carefully registered data products from simultaneous observations allow the EOS instrument teams to develop scientific approaches to better understand specific problems. There are six instruments on Aqua: (1) Atmospheric Infrared Sounder (AIRS), (2) Advanced Microwave Scanning Radiometer for EOS (AMSR-E), (3) Advanced Microwave Sounding Unit (AMSU), (4) CERES, (5) Humidity Sounder for Brazil (HSB), and (6) MODIS. As a cornerstone instrument for the EOS, MODIS is operated on both Terra and Aqua (Salomonson et al., 2002; Barnes et al., 2002; Parkinson, 2003).

The MODIS was designed and developed based on the desire of the science community to collect continuous global data for the studies of both short- and long-term changes in the Earth system. Its spectral bands and spatial resolutions were carefully selected in order

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to continue and enhance the observations of legacy sensors, such as the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR), the Landsat Thematic Mapper, the Nimbus 7 Coastal Zone Color Scanner (CZCS), and NOAA's High Resolution Infrared Radiation Sounder (HIRS). MODIS has 36 spectral bands: 20 bands with wavelengths from 0.41 μm to 2.2 μm are the reflective solar bands (RSB) and the 16 bands with wavelengths from 3.5 μm to 14.5 μm are the thermal emissive bands (TEB). It has three nadir spatial resolutions: 250 m for bands 1–2, 500 m for bands 3–7, and 1 km for bands 8–36. The equator crossing time of the Terra spacecraft orbit is 1030 LST descending southwards and that of the Aqua spacecraft is 1330 LST ascending northwards. With complementing morning and afternoon observations, the Terra and Aqua MODIS have greatly enhanced the ability to monitor the global environment and climate changes.

There are approximately 40 science data products generated from the observations of all the MODIS instruments. To ensure the quality of the data products, both Terra and Aqua MODIS went through extensive pre-launch calibration and characterization, including various tests at the component level, sub-system level, and thermal vacuum (TV) system level. In orbit, the instrument is calibrated and characterized using its on-board calibrators: a solar diffuser (SD) and a solar diffuser stability monitor (SDSM), a v-grooved flat panel blackbody (BB), and a spectro-radiometric calibration assembly (SRCA) (Barnes et al, 1998; Guenther et al., 1998; Xiong et al., 2003a; Xiong et al., 2005a; Che et al., 2003).

This paper provides an overview of MODIS pre-launch and in-orbit calibration and characterization activities as well as the level 1B (L1B) algorithms that convert instrument responses (digital numbers) to the calibrated data products (radiance and reflectance). It focuses on the radiometric calibration issues of both RSB and TEB. In-orbit monitoring of the detectors' responses and noise characterization, solar diffuser degradation, and the response versus scan angle (RVS) are discussed. Examples of both Terra and Aqua MODIS in-orbit performance are also presented. Topics related to instrument spectral and spatial calibration and characterization are not discussed in this paper. The experiences and lessons learned from MODIS instrument design, pre-launch and in-orbit calibration and characterization can be applied to future sensors in remote sensing, such as the Visible Infrared Imaging Radiometer Suite (VIIRS) for the National Polar-orbit Operational Environmental Satellite System (NPOESS) and the NPOESS Preparatory Project (NPP) missions.

7. Summary

The MODIS is one of the key instruments for NASA's EOS, designed from legacy sensors with improved spectral, spatial, and temporal resolutions. It is currently operating on both the Terra and Aqua satellites, making complementary morning and afternoon observations and providing the science community with continuous datasets for studying and better understanding the global environment and climate changes. MODIS has 36 spectral bands: 20 reflective solar bands and 16 thermal emissive bands that are calibrated and characterized in-orbit by a set of in board calibrators that include a solar diffuser and solar diffuser stability monitor system, a blackbody, and a spectro-radiometric calibration assembly. This paper has provided details of the MODIS instrument background, including its on-board calibrators and focal plane assemblies. It has presented an overview of MODIS pre-launch and in-orbit calibration and characterization activities and efforts, the L1B calibration algorithms, and lessons learned. The MODIS reflective solar band calibration is reflectance based. The band measurements are calibrated in orbit by the SD/SDSM system using a simple linear algorithm with response changes updated through L1B LUTs. The thermal emissive bands are calibrated on a scan-by-scan basis by the on-board blackbody using a quadratic algorithm. Examples of MODIS in-orbit performance are also provided in this paper, including SD degradation, mirror side response difference, RVS changes for the reflective solar bands, and the detectors' short- and long-term stability for the thermal emissive bands. In general, both Terra and Aqua MODIS have been performing well according to the specified design parameters mainly because of the extensive and constant calibration and characterization efforts. There is no doubt that the experiences and lessons learned from MODIS have addressed the importance of sensor calibration and characterization, from pre-launch and in orbit, and will benefit future remote sensing missions.