ELSEVIER

Remote Sensing of Environment 83 (2002)

Remote Sensing of Environment

www.elsevier.com/locate/rse

On-orbit performance of the Earth Observing System Moderate Resolution Imaging Spectroradiometer; first year of data

B. Guenther [a,*], X. Xiong [b], V.V. Salomonson [a], W.L. Barnes [a], James Young [c]

[a] NASA's Goddard Space Flight Center, Greenbelt, MD 20771, USA
[b] Science Systems Applications, Inc., Suite 104, 7501 Forbes Boulevard, Seabrook, MD 20706, USA
[c] Raytheon, Santa Barbara Remote Sensing, Building 32, 75 Coromar Drive, Goleta, CA 93117, USA

Received 5 April 2001; received in revised form 31 January 2002; accepted 1 March 2002

Abstract

The Moderate Resolution Imaging Spectroradiometer (MODIS) completed the first year of science data acquisition on February 24, 2000. The overall performance of the sensor and the on-board calibration systems for this first year have been very good. Several features of the performance lead to characteristics in the data set that merit special attention. These items are sometimes called data product caveats, and are described here. Uncertainty budgets for the 0.555-μm band, the 1.240-μm band and the 12.000-μm band are presented at several days throughout this first year. The uncertainty is estimated to be decreasing with time during this period, and to be near 1.8% in reflectance factor for 0.555 μm, 1.9% for the reflectance factor product for the 1.240 μm band, and 0.7% for the 12.000-μm band at nadir at the end of the first year. Degradation of the solar diffuser is 2.3% at 0.412 μm, known to an uncertainty of ± 0.5%. Solar diffuser degradation for wavelengths longer that 0.5 μm is indistinguishable from the uncertainty in trend determination for the first year. Mirror side degradation at 0.412 μm is 6 ± 0.5%, with a mirror side difference of an additional 3%. The performance present in the data at the end of year 1 provides significant encouragement that many improvements in our understanding of the Earth system performance can and will be based on MODIS data during the coming years.

1. Introduction

The Earth Observing System (EOS) was designed to provide observations that would enable better understanding on a global scale of the entire Earth system and the included processes. There was and there is urgency attached to this effort because an expanding human population is more affected by natural variability in the environment and, more importantly, has become an active participant in the evolution of the Earth system. To address questions that were both scientifically important, and relevant to resource management and sustainability policies, many sensors were designed with considerable attention to enhancing existing data bases for cloudiness, sea surface temperature, land cover, etc. Key among these sensors is the Moderate Resolution Imaging Spectroradiometer (MODIS) whose heritage comes from the NOAA Advanced High Resolution Radiometer (AVHRR), the Nimbus Coastal Zone Color Scanner (CZCS) and the Orbview-2 SeaWIFS sensor, the NOAA High-resolution Infrared Sounder (HIRS), and the Landsat Thematic Mapper. MODIS has been designed as a primary sensor to address questions related to: atmospheric variables such as cloud properties, radiative fluxes, and aerosol properties; land variables such as land cover and land use change, vegetation dynamics, surface temperature, fire occurrence, volcanic effects, and snow cover and, ocean variables such as sea surface temperature, and ocean color related to phytoplankton distribution and dynamics and photosynthetic efficiency.

MODIS was launched on the EOS Terra spacecraft on 18 December 1999. Initial engineering data was returned almost immediately, and science data was acquired first on 24 February 2000. The MODIS sensor has wide spectral range and wide spatial coverage, with 36 carefully selected bands to observe land, ocean, and atmosphere features on a global basis every 1–2 days (Table 1). The bands are distributed on four local plane assemblies (FPA), with wavelengths between 0.4 and 0.6 μm on the VIS FPA, 0.6–1.0 μm on the NIR FPA, 1.0–5.0 μm on the SW/MWIR FPA and 5.0–15.0 μm on the LWIR FPA. The MODIS measurements program is designed to provide a data set from which scientists can construct models of the Earth's global dynamics—atmospheric, oceanic and terrestrial—and predict changes. Characteristics of the MODIS are described

in Barnes, Pagano, and Salomonson (1998), and its prelaunch calibration is summarized in Guenther, Godden, Xiong, et al. (1998). The purpose of this paper is to summarize the MODIS first year performance in orbit and the resulting quality of the data.

The MODIS includes several calibration systems to provide on-orbit calibration. The early on-orbit performance of these calibration and characterization systems is provided in Section 2. The overall MODIS performance is described in Section 3. The uncertainty of the resulting radiometrically calibrated data product (Level 1B) is summarized for three bands, with the contributions of several known sensor features highlighted in that analysis. The detailed MODIS performance is described in Section 4. Actions taken to improve performance or better characterize the performance are highlighted, and cautions on how these features may be impacting the Level 1 data set are reviewed as well.

Table 1
Overall characteristics of the MODIS instrument and selected operational specifications

Primary use	Band	Bandwidth[a]	Special radiance[b]	Required SNR[c]	Primary use	Band	Bandwidth[a]	Spectral radiance[b]	Required NEΔT (K)[d]
Land/cloud/	1	620–670	21.8	128	Surface/cloud	20	3.660–3.840	0.45 (300 K)	0.05
aerosols boundaries	2	841–876	24.7	201	temperature	21	3.929–3.989	2.38 (335 K)	2
Land/cloud/	3	459–479	35.3	243		22	3.929–3.989	0.67 (300 K)	0.07
aerosols properties	4	545–565	29	228		23	4.020–4.080	0.79 (300 K)	0.07
	5	1230–1250	5.4	74	Atmospheric	24	4.433–4.498	0.17 (250 K)	0.25
	6	1628–1652	7.3	275	temperature	25	4.482–4.549	0.59 (275 K)	0.25
	7	2105–2155	1	110	Cirrus clouds	26	1.360–1.390	6	150[c]
Ocean color/	8	405–420	44.9	880	water vapor	27	6.535–6.895	1.16 (240 K)	0.25
Phytoplankton/	9	438–448	41.9	838		28	7.175–7.475	2.18 (250 K)	0.25
Biogeochemistry	10	483–493	32.1	802	Cloud properties	29	8.400–8.700	9.58 (300 K)	0.05
	11	526–536	27.9	754	Ozone	30	9.580–9.880	3.69 (250 K)	0.25
	12	546–556	21	750	Surface/cloud	31	10.780–11.280	9.55 (300 K)	0.05
	13	662–672	9.5	910	temperature	32	11.770–12.270	8.94 (300 K)	0.05
	14	673–683	8.7	1087	Cloud top altitude	33	13.185–13.485	4.52 (260 K)	0.25
	15	743–753	10.2	586		34	13.485–13.785	3.76 (250 K)	0.25
	16	862–877	6.2	516		35	13.785–14.085	3.11 (240 K)	0.25
Atmospheric	17	890–920	10	167		36	14.085–14.385	2.08 (220 K)	0.35
water vapor	18	931–941	3.6	57					
	19	915–965	15	250					

MODIS Technical Specifications
Orbit: 705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun synchronous, near-polar, circular.
Scan rate: 20.3 rpm, cross-track.
Swath dimensions: 2330 km (cross-track) by 10 km (along track at nadir).
Telescope: 17.78 cm diameter off-axis, afocal (collimated), with intermediate field stop.
Size: 1.0 × 1.6 × 1.0 m.
Weight: 228.7 kg.
Power: 162.5 W (single orbit average).
Data rate: 10.6 Mbps (peak daytime); 6.1 Mbps (orbital average).
Quantization: 12 bits.
Spatial resolution: 250 m (Bands 1–2); 500 m (Bands 3–7); 1000 m (Bands 8–36).
Design life: 6 years.

[a] Bands 1–19 are in nm; Bands 20–36 are in μm.
[b] Special radiance values are (W/m^2 μm sr).
[c] SNR = signal-to-noise ratio.
[d] NEΔT = noise-equivalent temperature difference.

5. Summary and conclusions

The completion of the first year of MODIS operations has demonstrated that the derived data products will enable significant improvements in our understanding of the Earth systems. Data sets for annual and longer-term performance likely will start near 1 November 2000. The noise charts presented in Section 3 indicate that the sensor is capable of low noise measurements at nearly all wavelengths. The sample uncertainty tables indicate that the Level 1 calibration products are expected to meet the very demanding uncertainty measurements under many geophysical conditions. On the other hand, Section 4 provides a list of areas where initial MODIS performance was different than expected, and where significant improvements were needed to allow the derived data to meet scientific expectations. Numerous improvements now are in place. Continued improvements are being sought for even better quality MODIS data. The documentation for these improvements is available from the MODIS and MCST web pages. MODIS may be the most complex instrument built and flown on a spacecraft for civilian research purposes, and the performance present in the data at the end of year 1 provides significant encouragement that many improvements in our understanding of the Earth system performance can and will be based on MODIS data during the coming years.