Uncertainty analysis of Terra MODIS on-orbit spectral characterization

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Abstract: MODerate resolution Imaging Spectro-radiometer (MODIS) has been operated on-board the Terra spacecraft since December 18, 1999 and Aqua MODIS since May 4, 2002. Both MODIS Relative Solar Bands (RSBs) and Thermal Emissive Bands (TEBs) are calibrated on-orbit by a set of on-board calibrations (OBCs) in radiometric, spatial and spectral modes, providing accurate measurements for scientific researches. The Spectro-Radiometric Calibration Assembly (SRCA) is one of the key OBCs which can be operated at all three calibration modes. When operating in spectral mode, the SRCA is utilized for MODIS On-Orbit Spectral Characterization (MOOSC), monitoring and measuring the center wavelength (CW) shift of each RSB throughout the entire mission. However, some uncertainties in the SRCA measurement may affect the precision of the results due to possible system degradation, mechanical/optical backlash, deformation, and optical performance change.

In this study, the instrument background and the algorithm for calculating the CW shift of RSBs using the SRCA measurements are briefly introduced. We analyze or estimate the impact on the final CW value caused by the uncertainties on the Terra MODIS on-orbit spectral characterizations, including cavity temperature variation, limited number of sample points, noise of background, and the variation of β and θ_{off}. The results show that the influence is small and the maximum uncertainty is less than 1nm.

The lessons we learned in this study provide helpful information and experiences for the sensors which have no on-orbit spectral characterization capability and the useful guidance for the next generation satellite remote sensors.

Keyword: MODIS, spectral characterization, SRCA

Introduction

MODIS is one of the key instruments of Earth Observing System (EOS) mission operated by National Aeronautics and Space Administration (NASA)[1,2]. The MODIS Pre-Flight Model (PFM) onboard the Terra spacecraft was launched on December 18, 1999 and its Flight Model (FM-1) onboard the Aqua spacecraft was launched on May 4, 2002. Both instruments are operated in a sun-synchronous orbit at an altitude of 705km, with equator crossing time at 10:30 AM (Terra spacecraft) and 1:30 PM (Aqua spacecraft). MODIS has three different nadir spatial resolutions: 250m (band 1-2), 500m (band 3-7), and l000m (band 8-36) and the number of detectors of each band corresponding to its spatial resolution are 40, 20, and 10, respectively[3,4]. MODIS views the earth with 36 spectral bands including twenty Reflective Solar Bands (RSBs) and sixteen Thermal Emissive Bands (TEBs), covering a spectral wavelength range from 0.41μm to 14.4 μm. These thirty-six bands are located in four Focal Plane Assembles (FPAs): Visible (VIS), Near-Infrared (NIR), Short- and Middle-wavelength IR (SMIR), and Long wavelength IR (LWIR).

Before launch, MODIS spectral characteristics were carefully calibrated by a ground-based equipment called Spectral Measurement Assembly (SpMA). The calibration includes measurements of band/detector CW, bandwidth, RSR both in-band and Out-Of-Band (OOB) responses. Table 1 listed the specifications of the CW and bandwidth (BD) (nm) for each MODIS bands.

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Table 1. The specification of MODIS band CW and bandwidth (unit s: nm)

	Specification		Tolerance	
Band	Center wavelength	Bandwidth	Center wavelength	Bandwidth
	λ_CW	λ_BW	Δλ_CW	Δλ_BW
1	645	50	±4.0	±4.0
2	858	35	±2.2	±4.3
3	469	20	±4.0	±2.8
4	555	20	±4.0	±3.3
5	1240	20	±5.0	±7.4
6	1640	24.6	±7.0	±9.8
7	2130	50	±8.0	±12.8
8	412	15	±2.0	±1.5
9	443	10	±1.1	±1.6
10	488	10	±1.2	±1.7
11	531	10	±2.0	±1.9
12	551	10	±5.0	±1.4
13	667	10	-2.0,+1.0	±1.7
14	678	10	±1.0	±1.7
15	748	10	±2.0	±1.9
16	869	15	±5.0	±4.3
17	905	30	±2.3	±5.4
18	936	10	±2.3	±5.6
19	940	50	±2.4	±5.6
26	1375	30	±6.0	±8.0

Prelaunch calibration is very important. However, these efforts are not terminated because these characterizations are subject to be changed on-orbit. It is true for its spectral characterization over 6+ years' operation of Terra MODIS and four years' operation of Aqua MODIS. The difference of environment from the ground to orbit brings evident change. For instance, long term exposure to the sunlight can cause change to the spectral characterization; degradation of components introduces complicated change to the optical performance. Monitoring and recalibrating are critical to ensure maintenance of the calibrated accuracy and precision throughout the mission.

MODIS instrument has the capability to track spectral characterization of the RSB from pre-launch to on-orbit and over lifetime by using the SRCA. With a change to its configuration, the SRCA can operate in three calibration modes: radiometric, spatial, and spectral. When the SRCA is operated in spectral mode, it can be used to measure the CW shift of RSB and to recover Relative Spectral Response (RSR) profiles. In the algorithm of computing the CW, several uncertainties may have the impact on the precision of the results such as the cavity temperature variation, limited number of sample points, background noise, and variation in the parameters of the monochromator. β and θ_{off} where β is the half angle between incident and diffractive beam and θ_{off} is the grating motor offset angle. These two critical parameters in grating equation determine the wavelength scale of the SRCA calibration for RSB. Like any other spectrum device, β and θ_{off} are very difficult to keep constant for each measurement because of possible mechanical backlash, deformation, and/or the optical performance of the components change.

In this study, we mainly focus on finding how these variables impact the CW precision. A brief introduction to the algorithm of computing the center wavelength is given in section two. Section three estimates the uncertainties caused by β and θ_{off} from both theoretical analysis and real on-orbit measurements.d Section four gives the uncertainties caused by other variables to the CW. The total CW shift of each RSB is summarized in the section five. A brief summary is provided in last section.

Algorithm of computing the center wavelength for each RSB

A main functions of the SRCA is to track the instrument spectral characterization change from pre-launch to on-orbit and throughout the mission. It is a unique device with capability of operating in radiometric, spatial, and spectral modes. When the SRCA is configured as a monochromator in spectral calibration mode, it measures the band/detector response to determine the CW shift of each RSB (Band 1-19, and 26).

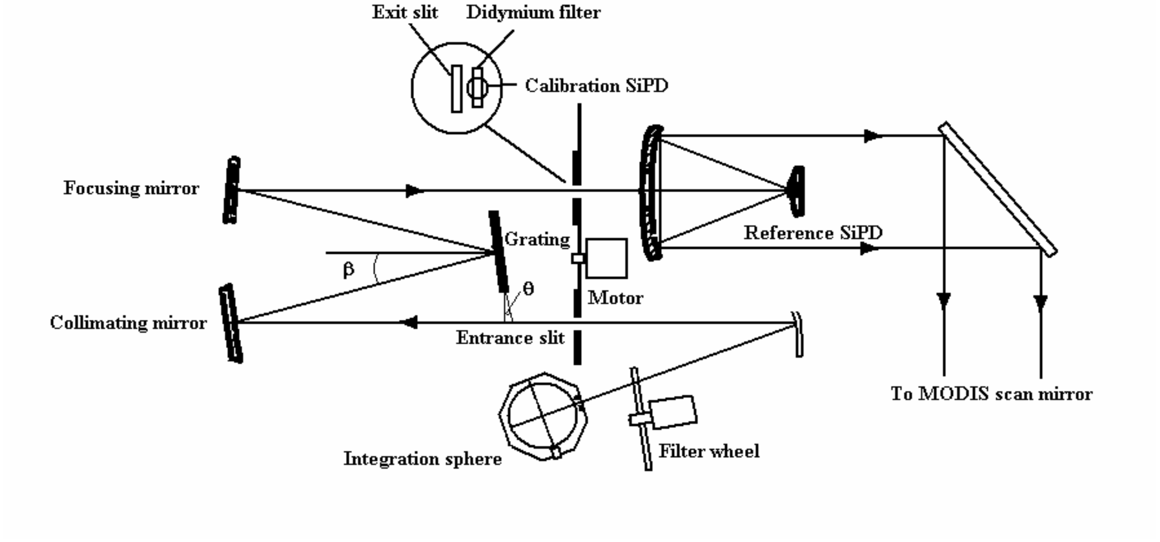

Figure 1. The layout of SRCA in spectral mode

The SRCA has three sub-components: a light source, a monochromator, and a collimator. Figure 1 is the structure of the SRCA. In spectral mode, two lamp configurations, 30W and 10W, are utilized in accordance with the Signal-to-Noise Ratio (SNR), the band location, number of sample points, and diffraction order for each band so that on-orbit operation is feasible. The beam from the Spherical Integration Source (SIS) focuses onto the entrance slit of the monochromator after passing through the diffraction order-sorting filters. Then the beam becomes collimated before reaching the grating. Diffracted by the grating, the monochromatic light at various spectrums is imaged onto exit slit plan in direction vertical to the slit width. When the grating is rotating, narrow spectrum output is from the exit slit which is located at the focus of a Cassegrain system. Then the beam output is collimated before reflected by the MODIS scan mirror to the band/detectors.

The SRCA have the wavelength self-calibration capability so that it can track the changes of instrument spectral characterization. There are two identical SiPDs: one is called reference Silicon Phote-diodes (SiPD) located at the secondary mirror of the Cassegrain system and the other named calibration SiPD located at exit slit plane and behind a slit, secondary slit. A didymium filter covers the slit with the calibration SiPD behind it. The light passes through the secondary slit and is received by calibration SiPD while the light from the main slit is sampled by reference SiPD. When the MODIS scan mirror is rotating, the two SiPDs take the data synchronizing with MODIS detector dn for each scan at different grating step positions. Since both calibration and reference SiPDs have the same spectral response, the light spectral profile can be removed by normalizing the calibration SiPD signal to the reference SiPD signal, shown in equation (1),

$$P_{didy,pk}(stp,m) = \frac{DN_{c,pk}(stp1,m) - DN_{c,dark}}{DN_{r,pk}(stp2,m) - DN_{r,dark}} \tag{1}$$

where stp is the grating step and pk is the peak number. $DN_{c,pk}(stp1,m)$ and $DN_{r,pk}(stp2,m)$ are digital number of calibration SiPD and reference SiPD respectively. The signal detected by two SiPDs when the SRCA lamp is off are expressed as $DN_{c,dark}$ and $DN_{r,dark}$

After normalization, calibration SiPD signal becomes the peak profile of the didymium $P_{didy}(\theta)$ which is the function of grating step. In each lamp configuration, we use three didymium peaks for self-wavelength calibration. The centroid value of three peaks $\overline{\theta}_{i,didy\_peak}$ in units of angle, can be calculated by the equation (2)

$$\overline{\theta}_{i,didy\_peak} = \frac{\sum_{\Delta\theta_i} P_{didy,i}(\theta)\cdot\theta\cdot\Delta\theta}{\sum_{\Delta\theta_i} P_{didy,i}(\theta)\cdot\Delta\theta} \tag{2}$$

where i is peak number, θ is the angle corresponding grating step, $\Delta\theta_i$ is the grating angle range over the peak region. Similarly, the centroid wavelength, $\overline{\lambda}_i$, for three didymium peaks can be calculated by Eq.(3)

$$\overline{\lambda}_i = \frac{\sum_{\Delta\lambda_i} T_{didy,i}(\lambda)\cdot\lambda\cdot\Delta\lambda}{\sum_{\Delta\lambda_i} T_{didy,i}(\lambda)\cdot\Delta\lambda} \tag{3}$$

The basic grating equation (4), links the three centroid wavelength $\overline{\lambda}_i$ and grating angle $\overline{\theta}_{i,didy\_peak}$.

$$\overline{\lambda}_i = \frac{A}{m}\sin(\overline{\theta}_{i,didy\_peak} + \theta_{off})\cos\beta \tag{4}$$

where A is the grating spacing (lines/mm); m is the grating order utilized. The three $\overline{\theta}_{i,didy\_peak}$ values in use are corresponding to the three didymium peaks. Using least-square fitting method can determine the angle values of β and θ_{off} which are utilized over the entire wavelength range for two different lamp configurations.

The response of the MODIS detectors to the SRCA illumination is spectrally modified by the light source, grating efficiency, and the SRCA transmittance. Hence, MODIS band response should be divided by the reference SiPD response and multipled by the SiPD spectral response to remove these effect using equation (5).

$$dn_{norm}(b,d,m,\lambda) = \frac{dn(b,d,m,\lambda)\cdot RSR_{Ref\_SiPD}(\lambda)}{dn_{Ref\_SiPD}(\lambda)} \tag{5}$$

where dn_{norm} is band/detector response after normalization; b, d, and m stand for band, detector, and scan mirror side, respectively. RSR_{ref_SiPD} is defined as the relative spectral response of the reference SiPD. The centroid wavelength of each band/detector can be computed with equation (3) by replacing T_{didy} with dn_{norm}.

In the algorithm, there are several parameters in the equation (4). Some of them are relatively stable or a constant and will have negligible impact on the accuracy of final results. They are the grating spacing, A, and diffraction order, m. Some of them may cause evidential impact to the final results, such as β and θ_{off}, limit sample points, noise of background , and temperature variation. We discussed the uncertainty caused by β and θ_{off} in the next section and by other variables in one section after.

Uncertainty caused by variation of β and θ_{off}

As described in section two, β and θ_{off} are two critical monochromator parameters in the grating equation. The theoretical value of β is 15.0 degree and that of θ_{off} is zero degree. The values of β and θ_{off}, however, deviate from each calibration due to instrumental and environmental variation, including limited measurement capability, possible mechanical/optical backlash, instrument component change, and cavity temperature variation. The variation of β and θ_{off} directly impact the final results when computing the CW of each RSBs using the measurements of the SRCA. In this section, the uncertainty caused by the variations of β and θ_{off} is calculated with theoretic analysis and on-orbit real measurements. The results calculated from two approaches are in good agreement.

1. Theoretical analysis

The grating equation is

$$\lambda = \frac{2A}{m}\sin(\theta + \theta_{off})\cos\beta \tag{6}$$

where θ is the grating angle corresponding to the different wavelength.

Differentiating equation (6) with respect to β, we have

$$\delta\lambda = -\frac{2A}{m}\sin(\theta + \theta_{off})\sin\beta\delta\beta \qquad (7)$$

Assuming that the value of β is changed from 14.8 to 15.2 degree and that of θ_{off} is kept at its theoretical value, the CW shift of all RSBs caused by variation of β is computed with the equation (7), shown in figure 2. The CW of each RSB will deviate to the long wavelength while the value of β decreases. The maximum uncertainty of CW could reach to 2nm (band 7) if β has 0.2 degree change.

Similarly, differentiating equation (6) with respect to θ_{off} gives

$$\delta\lambda = \frac{2A}{m}\cos(\theta + \theta_{off})\cos\beta\delta\theta_{off} \qquad (8)$$

The CW shift of all RSBs caused by variation of θ_{off} is computed with the equation (8), shown in figure 3 , by assuming that the value of θ_{off} is changed from -0.01 to +0.01 degree and that of β is kept at 15.0 degree.

2. On-orbit real measurements

In operation on-orbit, the SRCA measures the response signal dn of all bands/detectors in turn. The whole operation will be finished in the night time during four orbits. The number of samplings of each band is determined by the corresponding wavelength, bandwidth, grating order, and measure time.

In on-orbit measurements, there are some other factors that may cause uncertainty of β and θ_{off} . They are cavity temperature variation, limited number of sample points, and noise of background. We will discuss these variables and estimate their impact on the β and θ_{off} if they shift a small value from real measurement. According to the measurements available over six years for Terra MODIS, the total deviation range of β is less than ±0.1 degree and that of θ_{off} is less than ±1 step.

3. Other factors may cause uncertainties of β and θ_{off}

a) Dark voltage

As illustrated in section two, the peak profile of the didymium is derived by normalizing the calibration SiPD by the reference SiPD, shown in equation (1). In equation (1), the response of two SiPDs should subtract the dark signal before normalization. Therefore, the drift of background signal may produce the uncertainty to the value of β and θ_{off}. If the dark signal changes ±1%, the change of β and θ_{off} is listed in table 2.

In the table, the signal detected by the calibration SiPD is expressed as DN_dark_cal and that received by the reference SiPD is expressed as DN_dark_ref.

Table 2. the uncertainty of β and θ_{off} caused by dark signal of SiPD noise and drift

DN_dark_cal	DN_dark_ref	β (30w)	β (10w)	θ_{off} (30w)	θ_{off} (10w)
0%	+1%	0.00342	0.01865	0.00017	0.00081
0%	-1%	-0.00556	-0.01398	-0.00026	-0.00057
+1%	0%	-0.00193	-0.00516	-0.00009	-0.00023
+1%	+1%	0.00549	0.01256	0.00022	0.00050
+1%	-1%	-0.00575	-0.02375	-0.00031	-0.00108
-1%	0%	-0.00025	0.00621	0.00001	0.00027
-1%	+1%	0.00808	0.02437	0.00034	0.00101
-1%	-1%	-0.00272	-0.01149	-0.00016	-0.00055

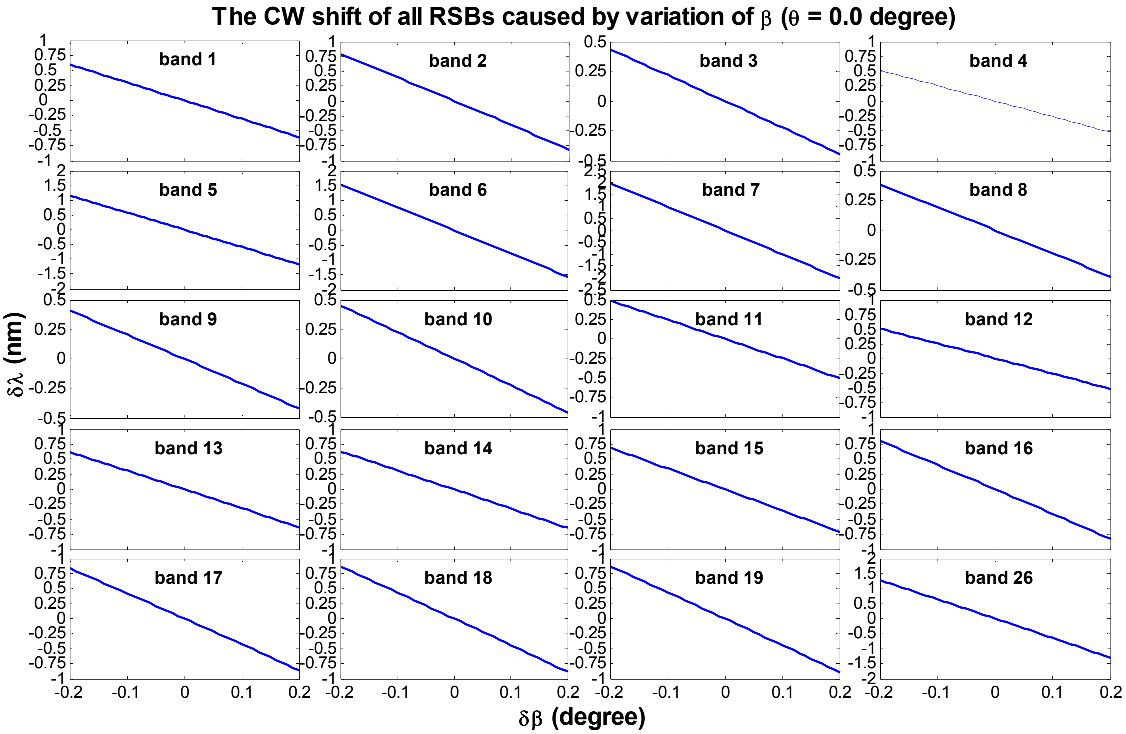

Figure 2. The center wavelength shift caused by the variation of β (θ = 0.0 degrees)

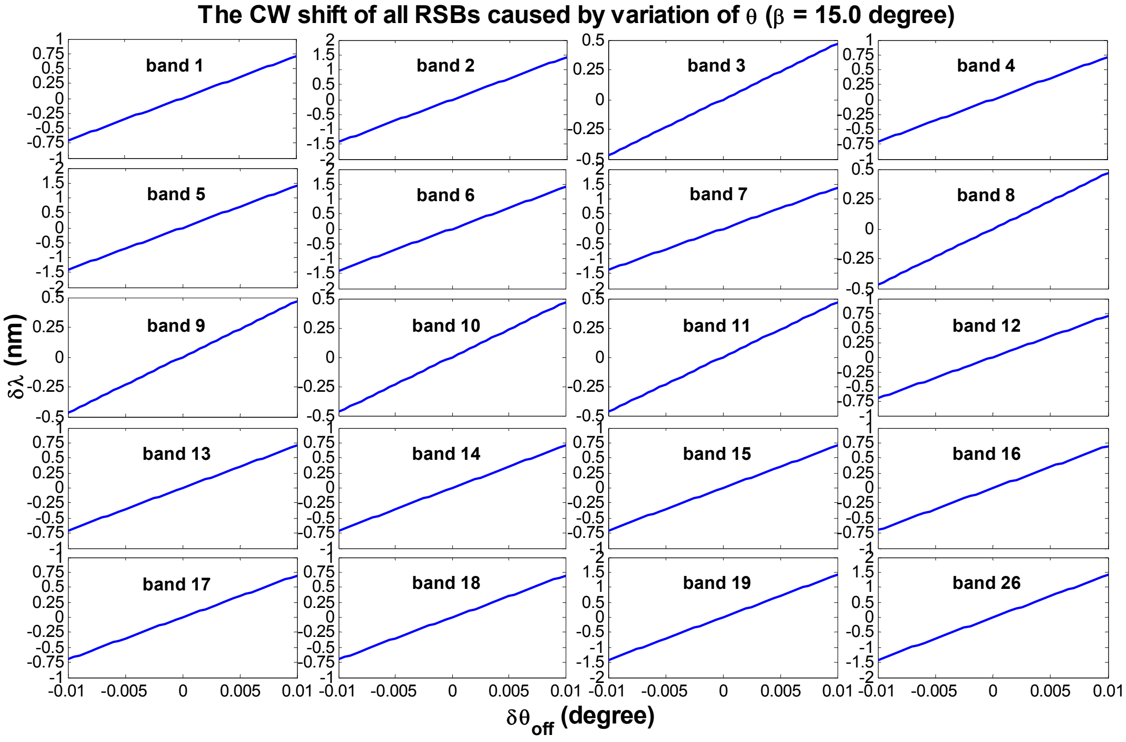

Figure 3. The center wavelength shift caused by the variation of θ (β=15.0 degrees)

b) Limited data points

The SRCA measures all RSBs spectral characterization in 4 orbits. When the SRCA is operated in spectral mode, a large amount of measurements should be taken in limited space-dark time period. The spectral calibration for each lamp configuration takes two orbits during which the grating is rotated uni-directionally to cover partial RSB and three didymium peaks. Time consuming especially occurs for short-wavelength band 8 where the SNR is very low. To improve the SNR, twenty-six scans per grating step are applied. For bands with grating angle overlapped but with different grating order takes time to rotate the order-sorting filter for each grating step in the range of the overlapping area. Thus, the sample data points have to be reduced. The sample range should cover where the RSR is greater than 0.3 and do not miss the peak or valley of the RSR. Because only a limited number of data points are applied and the data points corresponding to the low RSR region have no data, interpolation is very necessary to improve the results. Additionally, for consistency in our centroid calculation, all bands at different day take the same threshold to calculate the values of β and θ_{off}. Both cutting the spectral profile at the same threshold and different interpolation method may affect the value of the β and θ_{off}. Their impacts are given in table 3.

Table 3. the uncertainty of β and θ_{off} caused by limited data points

β (30w)	β (10w)	θ_{off} (30w)	θ_{off} (10w)
0.0064	0.01013	0.00023	0.00033

c) Temperature

SiPD temperature has been measured for spectral response correction purpose. However, the SiPD temperature sensors are not located at the same position as SiPDs. The temperatures values used are that measured by the thermal-couples at the nearest position of two SiPDs. Temperature difference exits between SiPD temperatures and that measured by the thermal-couples, especially when these SiPDs are under illumination. The temperature gradient can be even greater. Although the temperature correction has been introduced, the correction may have uncertainty due to lack of measurement data. A sensitivity set is given in Table 4 to estimate possible uncertainties of β and θ_{off}

Table 4. the uncertainty of β and θ_{off} caused by temperature deviation

		β (30w)	β (10w)	θ_{off} (30w)	θ_{off} (10w)
+0%	+3%	-0.00050	-0.00142	-1.8035E-05	-5.4894E-05
+0%	-3%	0.00050	0.00140	1.7812E-05	5.446E-05
+3%	0%	0.00019	0.00363	4.5771E-05	0.00020
+3%	+3%	-0.00031	0.00222	-1.3458E-05	0.00015
+3%	-3%	-0.00124	0.00503	-5.7692E-05	0.00025548
-3%	0%	-0.00019	-0.00043	-4.6299E-05	-1.4615E-05
-3%	+3%	-0.00070	-0.00184	-2.2665E-05	-6.9507E-05
-3%	-3%	0.00030	0.00098	1.3181E-05	3.9844E-05

d) The total uncertainty of β and θ_{offf}

With all the uncertainty sources considered, the variation of the values of β and θ_{off} are given in the table 5.

Table 5. The uncertainty of β and θ_{off} caused by noise deviation

	β (30w)	β (10w)	θ_{off} (30w)	θ_{off} (10w)
DN_dark	±0.01	±0.025	±0.00035	±0.001
Limit data points	±0.01	±0.01	±0.00025	±0.0004
Temperature	±0.0015	±0.005	±0.00001	±0.0003
Overall	±0.0215	±0.04	±0.00061	±0.0017

Unit : degree

e) The uncertainty caused by variation of β and θ_{off}

The total uncertainty of the CW caused by the variation of β and θ_{off} is shown is table 6. The two signs correspond to the change direction of the β and θ_{off} respectively. The sign '+' means positive value and the sign '-' means negative value. Based on the analysis above, the uncertainties caused by β and θ_{off} have opposite trend. The results shown in table 6 are consistent with the theoretical analysis. From the table, we know the maximum uncertainty caused by them appears when β and θ_{off} changes in different direction.

Table 6. The total uncertainty of β and θ_{off} (degree)

Band	+,+	+,-	-,-	-,+	Band	+,+	+,-	-,-	-,+
1	0.0163	-0.1014	-0.0163	0.1015	11	0.0041	-0.0739	-0.0041	0.074
2	0.1017	-0.4169	-0.1023	0.4165	12	0.0288	-0.2298	-0.0291	0.2296
3	0.0084	-0.0698	-0.0085	0.0697	13	0.0063	-0.2511	-0.0066	0.2516
4	0.0226	-0.0957	-0.0226	0.0957	14	0.0041	-0.2531	-0.0045	0.2528
5	0.0296	-0.486	-0.0303	0.4855	15	-0.0091	-0.2656	0.0087	0.2652
6	-0.0437	-0.555	0.0428	0.5543	16	-0.0319	-0.2868	0.0314	0.2863
7	-0.1367	-0.6407	0.1355	0.6397	17	-0.0015	-0.1179	0.0014	0.1177
8	0.0121	-0.0664	-0.0121	0.0664	18	-0.0451	-0.299	0.0445	0.2986
9	0.0101	-0.0684	-0.0101	0.0685	19	0.0866	-0.4306	-0.0872	0.4302
10	0.007	-0.0713	-0.0071	0.0712	26	0.003	-0.5113	-0.0036	0.5108

Uncertainty caused by other variables

Besides the β and θ_{off}, other variables including noise of the background, limited sample points, and cavity temperature variation can affect not only the value of β and θ_{off} but also the CW directly. The uncertainties of CW caused by these variables are listed in table7-9 respectively.

Comparing the results in the table 7-9, the impact of temperature deviation on the CW is so small that the uncertainty could be neglected. The reason is that a temperature correction has been executed to improve the measurements. The temperature correction is important and is necessary especially for MODIS bands 2 and 17 that has the largest temperature deviation (table 9). If no temperature correction was executed, the uncertainty of CW of band 2 and band 17 were as large as 0.1nm.

Additionally, the normalization is operated only for band 1-4 and 8-19 but not for the bands 5-7 and 26 because the SiPD spectral response was cut at about 1μm. Therefore, no specification required for these four bands. The uncertainty of CW caused by the temperature deviation for band 5-7 and band 26 are equal to 0. Actually, the lamp output for wavelength greater than 1μm is relative smooth. The estimated uncertainty of the CW is less than 0.03nm if the signal is normalized by a theoretical curve with temperature change by 10K for these four SWIR bands [5].

Results and discussion

In section three and four, we analyzed and calculated the impact caused by the several variables on the CW including β and θ_{off}, noise of background, limited sample points, and cavity temperature variation. The two monochromator parameters, either variation of β or θ_{off}, may produce relative large uncertainty of CW respectively. The impact by the other variables to the CW is relatively small. The total uncertainty of the CW for each RSB is listed in the table 10.

The total uncertainty of CW of all RSBs is less than 1nm. The specification of the SRCA requires that the SRCA can measure CW at a precision of $\lambda/0.412$ nm. According to the results in the table 10, the SRCA works well on-orbit and meet the required specification.

Table 7. The uncertainty of center wavelength caused by noise deviation

Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)
1	$\pm6\times10^{-2}$	6	$\pm2\times10^{-2}$	11	$\pm1\times10^{-2}$	16	$\pm3\times10^{-3}$
2	$\pm3\times10^{-2}$	7	$\pm1\times10^{-1}$	12	$\pm1\times10^{-2}$	17	$\pm2\times10^{-2}$
3	$\pm3\times10^{-2}$	8	$\pm3\times10^{-1}$	13	$\pm2\times10^{-3}$	18	$\pm3\times10^{-2}$
4	$\pm3\times10^{-2}$	9	$\pm4\times10^{-2}$	14	$\pm5\times10^{-5}$	19	$\pm1\times10^{-2}$
5	$\pm1\times10^{-2}$	10	$\pm1\times10^{-2}$	15	$\pm1\times10^{-3}$	26	$\pm4\times10^{-2}$

Table 8. The uncertainty of center wavelength caused by limited data points

Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)
1	$\pm1\times10^{-2}$	6	$\pm3\times10^{-2}$	11	$\pm2\times10^{-3}$	16	$\pm1\times10^{-3}$
2	$\pm2\times10^{-3}$	7	$\pm1\times10^{-2}$	12	$\pm2\times10^{-3}$	17	$\pm3\times10^{-3}$
3	$\pm4\times10^{-3}$	8	$\pm2\times10^{-2}$	13	$\pm2\times10^{-3}$	18	$\pm3\times10^{-3}$
4	$\pm2\times10^{-3}$	9	$\pm1\times10^{-2}$	14	$\pm2\times10^{-3}$	19	$\pm1\times10^{-2}$
5	$\pm1\times10^{-3}$	10	$\pm1\times10^{-3}$	15	$\pm1\times10^{-4}$	26	$\pm1\times10^{-1}$

Table 9. The uncertainty of center wavelength caused by temperature deviation

Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)
1	$\pm2\times10^{-4}$	6	0	11	$\pm1\times10^{-5}$	16	$\pm1\times10^{-4}$
2	$\pm2\times10^{-3}$	7	0	12	$\pm1\times10^{-6}$	17	$\pm1\times10^{-3}$
3	$\pm2\times10^{-5}$	8	$\pm1\times10^{-5}$	13	$\pm2\times10^{-6}$	18	$\pm5\times10^{-5}$
4	$\pm3.02\times10^{-6}$	9	$\pm3\times10^{-6}$	14	$\pm1\times10^{-5}$	19	$\pm2\times10^{-5}$
5	0	10	$\pm3\times10^{-6}$	15	$\pm3\times10^{-6}$	26	0

Table 10. The total uncertainty of CW of each band

Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)	Band	ΔCW (nm)
1	±0.172	6	±0.605	11	±0.086	16	±0.291
2	±0.451	7	±0.751	12	±0.242	17	±0.141
3	±0.104	8	±0.386	13	±0.255	18	±0.332
4	±0.128	9	±0.109	14	±0.255	19	±0.451
5	±0.497	10	±0.082	15	±0.267	26	±0.651

Summary

MODIS is one of the important satellite remote sensors that are widely used in diversified scientific research areas and multiple-discipline applications. A set of OBCs operate on-orbit for radiometric, spatial, and spectral characterization during mission lifetime guarantying the measurement accuracy. The SRCA, as one of OBCs, has capability of tracking the MODIS on-orbit spectral characterization as well as radiometric and spatial characterization.

In the algorithm for computing the CW of the RSBs, several variables may produce the uncertainty on the final results including cavity temperature variation, limited number of sample points, noise of background, and the variation of β and θ_{off}. The impact caused by them on the CW has been estimated. Among all variables, the uncertainty caused by the variation of β and θ_{off} is the largest and the contributions from the other variables are relative small.

The results from the performance and calibration of the SRCA on-orbit show that the spectral characterization of Terra MODIS measured by the SRCA has high confidence and the SRCA is operated normally and very stable so far. The spectral characterization has been well tracked.

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