# Uncertainty analysis of Terra MODIS on-orbit spectral characterization

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## Introduction

The Spectro-Radiometric Calibration Assembly (SRCA), one of the key On-Orbit Calibrators (OBCs), is utilized for MODIS On-Orbit Spectral Characterization (MOOSC) when operating in spectral mode. The SRCA measures the center wavelength (CW) shift and monitors the Relative Spectral Response (RSR) change for each Reflective Solar Band (RSB) throughout the entire mission. However, the uncertainties in the SRCA measurements can affect the quality of the results due to possible system degradation, mechanical/optical deformation, and optical performance change. In this study, we analyze and estimate the impact on the CW value by the uncertainties due to cavity temperature variation, limited number of sample points, background noise, and the variation of $\beta$ (the half angle between incident and diffractive beam) and $\theta_{off}$ (the grating motor offset angle). The results show that the influence is small and the maximum uncertainty is less than 1nm.

## Algorithm of computing the CW for each RSB

The layout of the SRCA is shown in figure 1. Two SiPDs are used for tracking the SRCA spectral profile. The peak profile of the didymium, the wavelength calibration filter, can be removed by ratioing the calibration SiPD signal to the reference SiPD signal, shown in equation (1)

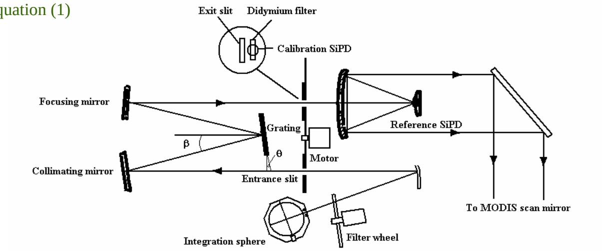



Figure 1. MODIS optical system

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

The centroid value of three peaks in units of angle, can be calculated by the equation (2) using the measured peak profile of the didymium $P_{didy}(\theta)$.

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

where $\theta$ is the angle corresponding grating step, $\Delta\theta_i$ is the grating angle range over the peak region.

The grating equation (3) links the three centroid wavelength $\bar{\lambda}_i$ and grating angle $\bar{\theta}_{i,didy\_peak}$

$$\bar{\lambda}_i=\frac{A}{m}\sin(\bar{\theta}_{i,didy\_peak}+\theta_{off})\cos\beta \quad (3)$$

where $A$ is the grating spacing (lines/mm); $m$ is the grating order utilized. Using least-square fitting method can determine the angle values of $\beta$ and $\theta_{off}$.

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 (4).

$$dn_{norm}(b,d,m,\lambda)=\frac{dn(b,d,m,\lambda)\cdot RSR_{Ref\_SiPD}(\lambda)}{dn_{Ref\_SiPD}(\lambda)} \quad (4)$$

where $b$, $d$, and $m$ stand for band, detector, and scan mirror side, respectively. The centroid wavelength of each band/detector can be computed with equation (3) by replacing $T_{didy}$ with $dn_{norm}$.

## Uncertainty caused by variation of β and θoff

### 1. The factors may cause uncertainties of β and θoff

In on-orbit measurements, there are some other factors that may cause uncertainty of $\beta$ and $\theta_{off}$, including temperature variation, limited number of sample points, and background noise. The impact caused by them on the $\beta$ and $\theta_{off}$ have been estimated and the results are listed in the tables 2-4, respectively.

| DN_dark_cal | DN_dark_ref | $\beta$ (30w) | $\beta$ (10w) | $\theta_{off}$ (30w) | $\theta_{off}$ (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 |

Table 2. the uncertainty (angle) of $\beta$ and $\theta_{off}$ caused by dark signal of SiPD noise and drift

| $\beta$ (30w) | $\beta$ (10w) | $\theta_{off}$ (30w) | $\theta_{off}$ (10w) |
|---|---|---|---|
| 0.0064 | 0.01013 | 0.00023 | 0.00033 |

Table 3. the uncertainty (angle) of $\beta$ and $\theta_{off}$ caused by limited data points

| $Temp\_SiPD_c$ | $Temp\_SiPD_r$ | $\beta$ (30w) | $\beta$ (10w) | $\theta_{off}$ (30w) | $\theta_{off}$ (10w) |
|---|---|---|---|---|---|
| +0% | +3% | -0.00050 | -0.00142 | -1.80E-05 | -5.49E-05 |
| +0% | -3% | 0.00050 | 0.00140 | 1.78E-05 | 5.45E-05 |
| +3% | 0% | 0.00019 | 0.00363 | 4.58E-05 | 2.00E-4 |
| +3% | +3% | -0.00031 | 0.00222 | -1.35E-05 | 1.50E-4 |
| +3% | -3% | -0.00124 | 0.00503 | -5.77E-05 | 2.55E-4 |
| -3% | 0% | -0.00019 | -0.00043 | -4.63E-05 | -1.46E-05 |
| -3% | +3% | -0.00070 | -0.00184 | -2.27E-05 | -6.95E-05 |
| -3% | -3% | 0.00030 | 0.00098 | 1.32E-05 | 3.98E-05 |

Table 4. the uncertainty (angle) of $\beta$ and $\theta_{off}$ caused by temperature deviation

### 2. The total uncertainty of β and θoff

With these uncertainty sources considered, the variation of the values of $\beta$ and $\theta_{off}$ are given in the table 5.

| | $\beta$ (30w) | $\beta$ (10w) | $\theta_{off}$ (30w) | $\theta_{off}$ (10w) |
|---|---|---|---|---|
| DN_dark | $\pm$0.0100 | $\pm$0.025 | $\pm$0.00035 | $\pm$0.00100 |
| Limit data points | $\pm$0.0100 | $\pm$0.010 | $\pm$0.00025 | $\pm$0.00040 |
| Temperature | $\pm$0.0015 | $\pm$0.005 | $\pm$0.00001 | $\pm$0.00030 |
| Overall | $\pm$0.0215 | $\pm$0.040 | $\pm$0.00061 | $\pm$0.00170 |

Table 5. The uncertainty (angle) of $\beta$ and $\theta_{off}$ caused by noise deviation

### 3. The CW uncertainty caused by variation of β and θoff

The total uncertainty of the CW caused by the variation of $\beta$ and $\theta_{off}$ is shown is table 6. The two signs correspond to the change direction of the $\beta$ and $\theta_{off}$ respectively. The sign '+' means positive value and the sign '-' means negative value.

| Band | +,+ | +,- | -,- | -,+ | Band | +,+ | +,- | -,- | -,+ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.016 | -0.101 | -0.016 | 0.102 | 12 | 0.029 | -0.230 | -0.029 | 0.230 |
| 2 | 0.102 | -0.417 | -0.102 | 0.417 | 13 | 0.006 | -0.251 | -0.007 | 0.252 |
| 3 | 0.008 | -0.070 | -0.009 | 0.070 | 14 | 0.004 | -0.253 | -0.005 | 0.253 |
| 4 | 0.023 | -0.096 | -0.023 | 0.096 | 15 | -0.009 | -0.266 | 0.009 | 0.265 |
| 8 | 0.012 | -0.066 | -0.012 | 0.066 | 16 | -0.032 | -0.287 | 0.031 | 0.286 |
| 9 | 0.010 | -0.068 | -0.010 | 0.069 | 17 | -0.002 | -0.118 | 0.001 | 0.118 |
| 10 | 0.007 | -0.071 | -0.007 | 0.071 | 18 | -0.045 | -0.300 | 0.045 | 0.299 |
| 11 | 0.004 | -0.074 | -0.004 | 0.074 | 19 | 0.087 | -0.431 | -0.087 | 0.430 |

Table 6. The CW uncertainty (nm) caused by $\beta$ and $\theta_{off}$ (degree)

## CW uncertainty caused by other variables

The uncertainties of CW caused by these variables are displayed in figures 2-4 respectively, including noise of the background, limited sample points, and cavity temperature variation.

The uncertainty of CW caused by limit data points

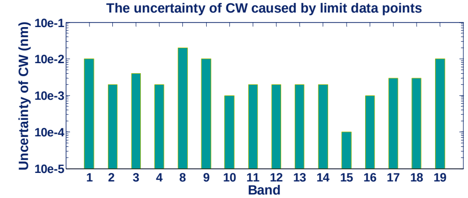



Figure 3. The uncertainty of CW caused by noise

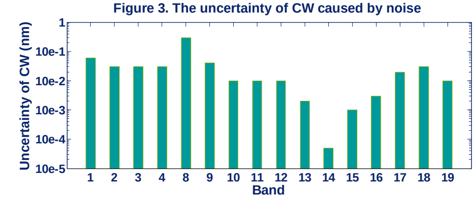
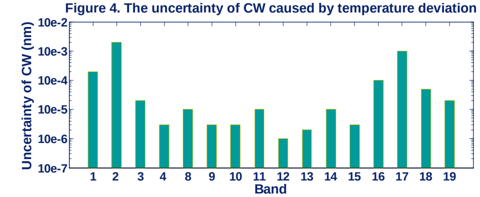


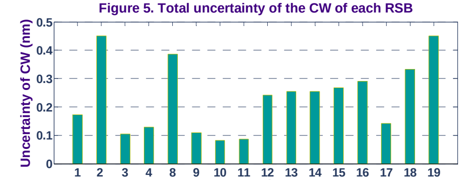

Figure 4. The uncertainty of CW caused by temperature deviation




## Results and discussion

The total uncertainty of the CW for each RSB is shown in figure 5.

Figure 5. Total uncertainty of the CW of each RSB




## Summary

1. Briefly introduce the methodology of computing the CW for each RSB using the SRCA.

2. An comprehensive uncertainty analysis has been studied.

3. The results form the uncertainty analysis and the SRCA on-orb spectral performance show that the spectral characterization of Terra MODIS measured by the SRCA has high confidence.

## Acknowledgement

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