Radiometric Cross-calibration of MODIS and CMODIS Based on Dunhuang Test Site

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Abstract

This paper presents a methodology for radiometric cross-calibration of the solar reflective spectral bands of Moderate Resolution Imaging Spectroradiometer (MODIS) and Chinese Moderate Resolution Imaging Spectroradiometer (CMODIS) sensors based on analysis of two difference time image pair for Dunhuang test site on July 27, 2002. With the well-calibrated MODIS as a reference, we derive top-of-atmosphere(TOA) reflectance using MODIS data and then use these TOA reflectance to compute TOA radiance for CMODIS taking into account the effect of spectral band different and the changes in solar zenith angle due to any temporal differences in the overpass times as well as differences in the view angles between the sensors. This TOA radiance, which is correlated with the sensor digital number (DN) output, determines the in-flight calibration coefficients of CMODIS. The relatively error between the cross-calibration and the reflectance-based method calibration results is within 9%.

1. Introduction

With the enhancement of launching, China launched meteorology and earth resource satellite in recent years. Launched on March 25,2002, the first Chinese Moderate Resolution Imaging Spectroradiometer (CMODIS) aboard the ShenZhou-3 (SZ-3) spacecraft has 34 bands with wavelength in the range of 403$\sim$12500 nm. CMODIS stopped operating in September 2002, after 6 months of operation. CMODIS is mainly applied to aspect and so on land utilization, land cover, water pollution monitor and resources investigation research. In-flight period CMODIS had obtained the massive data. In-flight radiometric calibration is imperative to quantities the data with higher accuracy and enable wide application.

Many methods have been proposed and used for the in-flight radiometric calibration of satellite sensors. The typical method for sensors calibration is the reflectance-based approach in which ground-based measurements of surface reflectance and atmospheric propertied are used in a radiative transfer model to predict an at-sensor radiance[1,2]. New methodologies continue to evolve [3]. The objective of in-flight cross-calibration is to provide a comparison between the in-flight calibration of imaging sensors that cover part or all of the same spectral region. By providing such a comparison, the extent to which calibration differences between well-characterized sensors producing the same data products at different scales will be known.

This paper describes a cross-calibration methodology applicable to two different time image pair for Dunhuang test site on July 27, 2002. The main results consist of CMODIS calibration coefficients in the seven solar reflectance spectral bands referenced against well-calibrated MODIS calibration coefficients in corresponding spectral bands.

2. The Dunhuang Test Site

The Dunhuang test site used in this work is located in 20 km northwest of Dunhuang in Gansu province. The coordinates of it are 40.08°N latitude and 94.38°E longitude. It has been in use for vicarious calibration since the mid-1990s. The overall size of the playa is approximately 20 km$\times$30 km, and it is located at an elevation of approximately 1.19 km in a geographical region with reasonably high expectations of clear weather and typically low levels of aerosol loading. The test site has preferable stability of surface reflectance because very homogeneous of surface in Fig.1. Fig.2 illustrates the measured surface reflectance.

3. Cross-calibration Approach

3.1 Radiometric formulation

Figure 1: The component of Dunhuang test site.

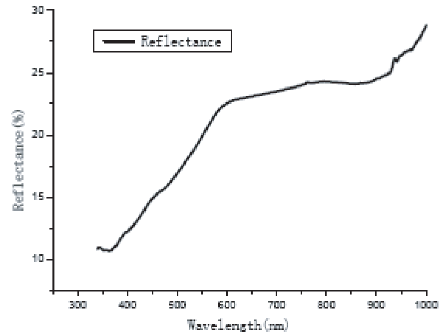

Figure 2: The measured ground reflectance of Dunhuang test site.

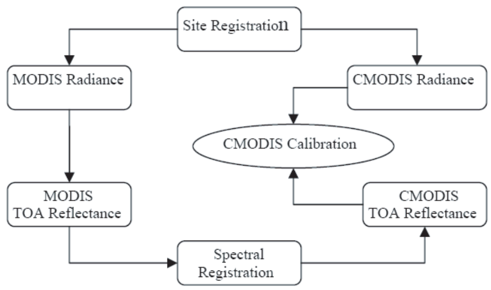

Figure 3: The cross-calibration approach.

TOA radiance L_i [in W/m^2 sr μm] are related to image data by Eq.1

$$L_i = A_i DN_i \tag{1}$$

where A_i is band-averaged sensor responsivity (in counts per unit radiance) and DN_i is the sensor digital number output (in count). TOA reflectance is related to TOA radiance by Eq.2

$$\rho_i = \frac{\pi \cdot L_i \cdot d_s^2}{E_{0i} cos\theta} \tag{2}$$

where E_{0i} is the exo-atmospheric solar irradiance in spectral band i [in $W/(m^2 \mu m)$] based on the Modtran-3 spectrum, θ is the solar zenith angle, and d_s is the Earth-Sun distance in astronomical units. A combination of Eqs.1-2 yields

$$\rho_i = \frac{\pi \cdot A_i \cdot DN_i \cdot d_s^2}{E_{0i} cos\theta} \tag{3}$$

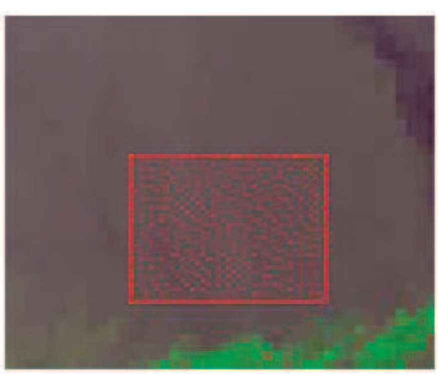

Figure 4: The test site common of MODIS data.

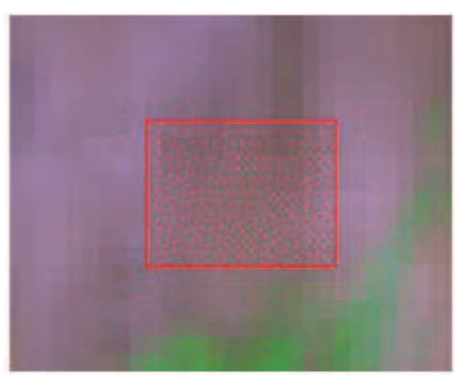

Figure 5: The test site common of CMODIS data.

There are two advantages to using reflectance instead of radiances [4]. One advantage is to remove the cosine effect of differences solar zenith angles due to the 111 min time difference between data acquisitions. The other advantage is to compensate for different values of exo-atmospheric solar irradiance arising form spectral band differences.

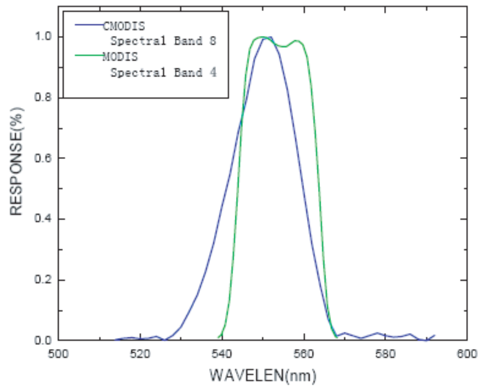

Figure 6: Spectral response of MODIS spectral band 4 and CMODIS spectral band 8

3.2 Cross-calibration

MODIS is a key instrument aboard the Terra satellite. Terra's orbit around the Earth is timed so that is passes from north to south across the equator in the morning. Terra MODIS is viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands ranging in wavelength from 400 nm to 14400 nm. These data will prove our understanding of global dynamics and processed occurring on the land, in the oceans, and in the lower atmosphere.

Table 1: The derived TOA reflectance of MODIS

Spectral band	Band 1(620-670nm)	Band 2(841-876nm)	Band 3(459-479nm)	Band 4(545-565nm)
Exo-atmospheric Solar Irradiance	1602	9903	2017.5	1860.5
A_i	0.0273426	0.0104566	0.0212364	0.0182111
DN_i	4373	7166	6458	6943
TOA reflectance	0.234	0.244	0.219	0.219

Table 2: The derived TOA reflectance and calibration coefficient of CMODIS

Spectral band	Band 4 (473 nm)	Band 8 (553 nm)	Band 9 (573 nm)	Band 11 (613 nm)	Band 13 (653 nm)	Band 18 (753 nm)	Band 22 (853 nm)
TOA refelctance	0.219	0.219	0.22	0.222	0.225	0.236	0.248
Exo-atmospheric Solar Irradiance	2003	1865.8	1824.8	1728.5	1575.5	1252.9	1016
DN_i	1568	1925	1937	2493	2394	1649	975
A_i	0.0563	0.0429	0.042	0.031	0.0299	0.0362	0.0522

As already mentioned, MODIS and CMODIS have similar spectral bands and spectral range. MODIS data is used here calibration to the CMODIS data. Fig.3 illustrates this approach. Philosophically, the approach is similar to that described by Teillet et al[3,5].

The first step in the cross-calibration process is to select the test site common to the two sensors. Ideally, the data from both sensors would be coincident in time with identical view and solar geometries. The near-coincidence in view geometry and 111 min in time two sensors leads to some uncertainties for the Dunhuang test site. The specific area of the test site common described Fig.4 and Fig.5. The DN_i for use in Eq.3 was obtained from large areas in common between MODIS and CMODIS data pairs.

There are significant differences in relative spectral response profiles between corresponding MODIS and CMODIS spectral bands. The effects these spectral band differences have on measured TOA reflectance depend on spectral variations in the exo-atmospheric solar illumination. The TOA reflectance derived from Eq.3 of CMODIS are spectral registration using the results of MODIS. Fig.6 describes an example that is a different spectral response between MODIS spectral band 4 and CMODIS spectral band 8.

3.3 Results

Though Eq.3 and correlate parameters, TOA reflectance of MODIS can be obtained. Table.1 gives the derived TOA reflectance for four the bands of MODIS. Used these TOA reflectance and spectral registration compute TOA reflectance for CMODIS, which are correlated with DN_i, determine the in-flight calibration coefficients (A_i) of CMODIS, which are listed in Table. 2.

Table 3: The relatively error between cross-calibration approach and reflectance-based approach

Spectral band	Band 4 (473 nm)	Band 8 (553 nm)	Band 9 (573 nm)	Band 11 (613 nm)	Band 13 (653 nm)	Band 18 (753 nm)	Band 22 (853 nm)
A_i by reflectance-based approach	0.052	0.04	0.0389	0.029	0.0289	0.0332	0.0488
A_i by crosscalibration approach	0.0563	0.0429	0.042	0.031	0.0299	0.0362	0.0522
Relatively error	0.0827	0.0725	0.0797	0.069	0.0346	0.09	0.0697

4. Conclusion

A cross-calibration methodology has been formulated and implemented to used image pairs to radiometrically calibrate CMODIS with respect to MODIS. The use of large areas common to both MODIS and CMODIS image data successfully reduce uncertainties due to image misregistration. The most limiting factor in the approach is the need to adjust for spectral band differences between the two sensors, which require knowledge about the spectral content of the scene. Rangeland, grassland, sand, playa, and snow are potentially good candidates for radiometric cross-calibration.

Table.3 shows that the relatively error between the cross-calibration approach and reflectance-based approach calibration results is within 9%. The present study indicates that the cross-calibration approach can provide a valuable "contemporary" calibration for CMODIS in visible and near-infrared spectral bands based on the excellent radiometric performance of MODIS.

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