Remote Sensing of Environment xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Cross-calibration of reflective bands of major moderate resolution remotely sensed data

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ARTICLE INFO

Keywords:
AOD
BRDF
Cross-calibration
MODIS
Synergy
Multi-sensor
VIRR
MERSI
AVHRR
Moderate resolution

ABSTRACT

The major global biogeophysical products obtained from remote sensing are usually composites of 8 or 16 days, and are almost always retrieved from a single sensor. Subsequently, the applications of these products are limited in cases requiring higher temporal frequency. With the increasing number of freely available moderate resolution remote sensing datasets, multi-sensor synergy to increase temporal sampling is warranted. However, radiometric consistency of multi-sensor data is not as good as expected; therefore, first the constituency should be evaluated. A new cross-calibration approach of reflective bands for moderate resolution remotely sensed data is proposed in this paper. The new approach uses a time series of MODIS data from both Terra and Aqua to retrieve both the bidirectional reflectance distribution function (BRDF) and aerosol optical depth (AOD) simultaneously over an invariant desert target. The MODIS retrieved BRDF and AOD are then used to cross-calibrate the medium resolution spectral imager (MERSI) and visible and infra-red radiometer (VIRR) onboard FengYun3-A and B satellites (FY3A/B) and advanced very high resolution radiometer (AVHRR) onboard NOAA-16, 17, and 18. The cross-calibration method is validated in two ways: 1) by comparing with the vicarious calibration; and 2) the top of atmosphere (TOA) reflectance before and after calibration, which show that the calibration error of this new approach is consistent within 5%. Compared with most cross-calibration methods, our new method is generic and better consider on BRDF models; furthermore, the well-built BRDF of the calibration site and simultaneously retrieved AOD make the method fully automatic and cost effective for the calibration of most moderate resolution remote sensors, especially Chinese sensors.

1. Introduction

Monitoring the terrestrial environment at the global level is the particular task of satellites with moderate spatial resolution sensors. The advanced very high resolution radiometers (AVHRRs) onboard NOAA series satellites were the first to be made operational; therefore, global terrestrial biogeophysical products with 1 km spatial resolution have been important records of terrestrial dynamics since 1980s (Townshend, 1994). The MODIS sensors as the second generation of sensors include some substantial improvements including more settings of spatial resolution, more spectral bands, narrower bandwidths, better radiometric capability, and more elaborate bio-geophysical products (Townshend and Justice, 2002). Other moderate spatial resolution sensors have also been in operations in recent years, including the VEGETATION instruments onboard SPOT, AATSR and MERIS onboard ENVISAT, and the MERSI and VIRR onboard the FengYun3 (FY3). Most of these moderate resolution sensors have their own bio-geophysical products. Among these products, the MODIS is the most popular because it is easily and freely accessible. However, these products are based on data from single-type sensors, and do not include the advantages of using multiple data from different sensors in a synergized way, data such as higher temporal frequency, more angular information, and so on. Increasingly long-term biogeophysical products will be created by taking advantages of remote sensing data from multiple instruments (Townshend et al., 2002). Fig. 1 shows an example of the advantages gained by using multi-sensor data. The figure draws out the distribution of the viewing zenith and azimuth angles of the multi-sensor dataset including MODIS/Terra (green), MODIS/Aqua (blue), FY3A/VIRR (red), and FY3A/MERSI (black). The compositing period is 3 to 8 days for three different pixels (38.88°N, 100.40°E; 38.50°N, 100.82°E; and 39.38°N, 99.75°E) in the polar coordinate system. A longer compositing period and more sensors produces more observations, which constructs better angular distribution for the bidirectional reflectance distribution function (BRDF) fitting in a shorter period of time. The results will better fit the variation of vegetation in the growing season. Furthermore, the angular information from multi-

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http://dx.doi.org/10.1016/j.rse.2017.10.014
Received 14 February 2017; Received in revised form 27 September 2017; Accepted 13 October 2017

Please cite this article as: Zhong, B., Remote Sensing of Environment (2017), http://dx.doi.org/10.1016/j.rse.2017.10.014

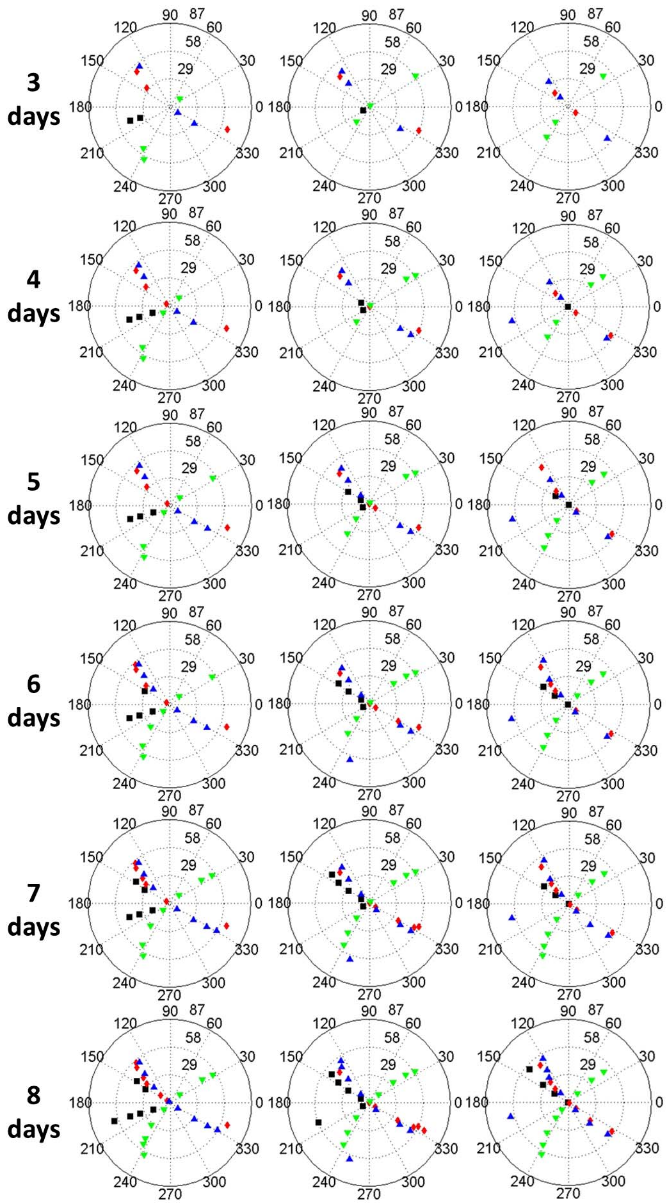

Fig. 1. The distribution of the viewing zenith and azimuth angles of the multi-sensor dataset including MODIS/Terra (green), MODIS/Aqua (blue), FY3A/VIRR (red), and FY3A/MERSI (black). The compositing period is 3 to 8 days for three different pixels in the polar coordinate system. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sensor data is more evenly distributed, so it will benefit the BRDF fitting accuracy and subsequently improve the accuracy of bio-geophysical parameters.

As more and more moderate-resolution sensors onboard different satellites with global observing capability are placed in orbit, many studies on biogeophysical variables and global climate change through multi-sensor observations have been aggregated. However, the radiometric calibration differences between sensors can cause differences in the bio-geophysical parameter values, which cause discrepancies when sensor parameters are merged (Kawamura et al., 2005; Gallo et al., 2004). Yang et al. (2017) evaluated some of the moderate-resolution sensors and the discrepancy in radiometry is quite obvious. Consequently, to maintain consistency, radiometric cross-calibration among different sensors should be performed before data are used together.

Within these sensors, the AVHRR onboard NOAA has retrieved more than 40 years of global data, which is the longest record of global earth surface observation by remote sensing instrument. However, AVHRR lacks an onboard calibration system for the visible to near infrared (NIR) bands. To get accurate radiometric calibrated continuous AVHRR data, many vicarious calibration methods have been developed, including methods based on an invariant target (Rao and Chen, 1999; Heidinger et al., 2002; Vermote and Saleous, 2006) and methods based on simulating the ocean signal (Vermote and Kaufman, 1995). Calibration errors were reported to be controlled within 5% by these different methods (Vermote and Saleous, 2006); however, these methods require an intense volume of data, processing, and monitoring.

FY-3 is the second Chinese polar orbiting meteorological satellite and it is capable of observing the earth globally with multispectral bands. MERSI has 20 spectral bands including 19 reflective bands and one thermal band. MERSI has been calibrated annually through a vicarious calibration based on synchronous in-situ measurements at the China Radiometric Calibration Site (CRCS), which is located at Dunhuang Gobi Desert, centered at 40.65°N, 94.35°E (Hu et al., 2010). Although the CRCS based vicarious calibration has an error within 5%, the limited data are not enough for frequent and stable in-flight calibration coefficient updates.

The MODIS instrument has an onboard calibration system that promises an absolute error better than 2% (Guenther and Xiong, 2002). Therefore, MODIS as a well calibrated instrument is very practical for radiometric cross-calibrating sensors that lack a good onboard calibration system by using invariant targets, such as desert and ice. A method using coincident acquisitions of MODIS and AVHRR near nadir over Alaska and Siberia was proposed (Heidinger et al., 2003). Vermote and Kaufman (1995) proposed a cross-calibration method using a time series of MODIS and AVHRR data over a Saharan Desert site.

In this study, the time series of MODIS both from Terra and Aqua are first used to retrieve the BRDF and aerosol optical depth (AOD) simultaneously (Liang et al., 2006; Zhong et al., 2007) over the Badain Jaran Desert. The BRDF is then used to simulate the surface reflectance under the target sensor's solar illumination and view geometries. Third, the simulated surface reflectance is recalculated to the top of atmosphere (TOA) reflectance using the atmosphere radiative transfer model based on the retrieved AOD at the first step and the MODIS atmospheric water vapor content product (MOD05). At last, the cross-calibration of the target sensor is performed. The flowchart of this cross-calibration method is showed in Fig. 2. The cross-calibration method is validated in two ways: 1) by comparing with the vicarious calibration; and 2) by comparing the TOA reflectance before and after calibration. In this study, the cross-calibration method is applied to the major moderate satellite sensors including MERSI and VIRR of FY3A/B and AVHRR of NOAA.

2. Calibration site's BRDF retrieval

2.1. Calibration site introduction

A portion of the Badain Jaran Desert approximately 40 km × 100 km was chosen as the calibration site. The location is shown in Fig. 3 and as are the true color composites using MODIS and Landsat-7/ETM + Imagery. This calibration site has been used extensively for cross-calibration of Chinese moderate to high spatial resolution satellite instruments, such as HJ-1/CCD (Zhong et al., 2014) and GF-1/WFV (Yang et al., 2017). The validity of the site as a calibration site has been verified by Zhong et al. (2014). Bhatt et al. (2014) also states that the Badian Desert as observed by Aqua-MODIS has a