

Evaluation of MODIS VI Products Using the AERONET-based Surface Reflectance Validation Network Dataset

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Abstract - MODIS vegetation index (VI) products (MOD13) are widely used in many science applications that aim to monitor and characterize spatial and temporal vegetation dynamics from space. The quality and reliability of the MODIS VI products are vital to these studies, and thus there is a need to assess their quality. In this study, the AERONET-based Surface Reflectance Validation Network (ASRVN) dataset is used to evaluate the quality of the MODIS 1 km, 16-day composite NDVI and EVI products. Our results show a positive bias of red reflectances, which is responsible for bias in the MODIS NDVI and two-band EVI (EVI2). The negative bias of the MODIS blue reflectance nullifies this effect on the standard EVI, resulting in insignificant bias in EVI. EVI and NDVI temporal profiles match ASRVN VI profiles even during higher aerosol optical thickness (AOT) periods, indicating that the VI products are not significantly affected by aerosols.

Keywords: EVI, NDVI, Aeronet, ASRVN, MODIS

1. INTRODUCTION

The Earth Observing System (EOS) is a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument onboard the EOS Terra and Aqua satellites launched in 1999 and 2002 respectively (Justice et al., 2002). As a standard MODIS land product, the MODIS vegetation index (VI) (i.e. MOD13) product is designed to provide consistent, spatial, and temporal comparisons of global vegetation conditions that can be used to monitor photosynthetic activity (Justice et al., 1998; Huete et al., 2002). Two MODIS VIs, the normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI), are produced globally over land at resolutions from 250 m to 0.05 degree in 16-day and monthly compositing periods for the collection 5 (<https://wist.echo.nasa.gov/api/>).

NDVI is referred to as the “continuity index” to the existing historical National Oceanic and Atmosphere Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR)-derived NDVI time series since 1981 (Huete et al., 2002).

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \quad (1)$$

where ρ_{NIR} and ρ_{Red} are the Near-infrared (NIR) and red reflectances, respectively.

NDVI is widely used in scientific applications such as climate-vegetation interactions, estimation of vegetation biophysical parameters, and land use and land cover change. However, several limitations of NDVI have been documented, including sensitivity to soil background and atmospheric contaminations, insensitivity (saturation) to vegetation signals in high biomass vegetated areas, and nonlinear relationship with such biophysical characteristics as vegetation fraction and leaf area index (LAI).

To overcome the problems encountered by NDVI, EVI was developed to optimize the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmosphere influences (Huete et al., 2002).

$$EVI = 2.5 \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + 6\rho_{Red} - 7.5\rho_{Blue} + 1} \quad (2)$$

where ρ_{Blue} is the blue reflectance. EVI proved more sensitive to dense vegetation, less sensitive to aerosol contaminations (Xiao et al., 2003), and more linearly related to LAI than NDVI.

Use of EVI is limited to instruments with a blue band. A two-band EVI (EVI2) was developed to optimally approximate the three-band EVI without using a blue band and maintain the soil-adjustment function and linearity of EVI (Jiang et al., 2008).

$$EVI2 = 2.5 \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + 2.4\rho_{Red} + 1} \quad (3)$$

It can be used as a substitute of EVI when atmosphere effects are insignificant or corrected accurately in the red and NIR bands. These unique characteristics enable the extension of EVI to instruments without a blue band for generating a backward compatibility of EVI to the historical AVHRR record.

Recently extensive remote sensing validation networks have been established globally in a wide variety of land cover types, including the EOS land validation core sites (Morissette et al., 2002), Fluxnet (Baldocchi et al., 2001), Baseline Surface Radiation Network (BSRN) (Ohmura, et al., 1998), Aerosol Robotic NETwork (AERONET) (Holben et al., 1998) and AERONET-based Surface Reflectance Validation network (ASRVN) (Wang et al., 2009).

2. DATA AND METHODS

2.1 Site selection

40 AERONET sites where ASRVN data is available for several years were selected globally to evaluate the uncertainty of MODIS VI product (Fig. 1). These sites include a wide variety of land cover types and are distributed all around the world to represent various climatic and geographic conditions. Some of sites are also used as EOS land validation core sites, FLUXNET and BSRN sites.

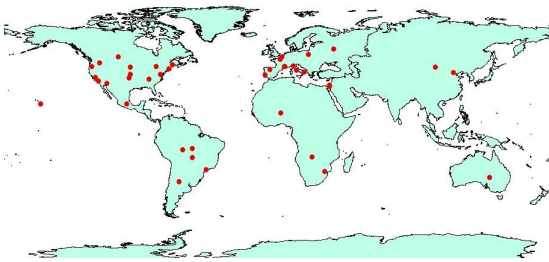


Figure 1. Location of 40 AERONET sites where ASRVN data are generated.

2.2 MODIS VI extraction

MODIS 1 km, 16-day composite vegetation index product (MOD13A2) from collection 5 and the Terra platform between 2000 and 2008, are extracted over the 40 sites. The MODIS standard VI product include two, gridded vegetation indices (NDVI, EVI), product quality assessment (QA), composite day, input red (band 1), NIR (band 2), blue (band 3), and middle-infrared (MIR) (band 7) reflectances, and sensor view, solar zenith and relative azimuth angles for each pixel. In this study, the MOD13A2 red, NIR and blue reflectances, sensor zenith angle, relative azimuth angle, QA and composite day of year (DOY) (on which the quality of MODIS VI data is considered to be the best during a 16-day compositing period by the MODIS compositing algorithm to represent the 16-day period) in the windows of 5×5 MODIS 1-km pixels, centered at the 40 AERONET sites, are extracted for the evaluation of the MODIS VI product.

Only good quality pixels are used to generate the average reflectances of each 5×5 km² window centered at the

AERONET sites, from which the VI values are calculated for each site at 16-day intervals. Good quality pixels are defined as those with VI usefulness index as 'acceptable quality', aerosol quantity=01 (low aerosol quantity), no mixed clouds, no snow/ice, no cloud shadow and view zenith angles less than 40°. Since the MODIS vegetation index product is composited within 16-day periods, pixels within 5×5 windows may be chosen from different days in some cases. So the sun and sensor geometry of pixels may be different from one pixel to another pixel. However, most of the pixels in the relative small 5×5 window are chosen on the same day by the compositing algorithm, which is defined as the mode composite DOY. In order to compare 16-day MOD13A2 VI product with VIs calculated from the daily ASRVN reflectances, only pixels composited on the mode composite day with good quality in each 5×5 window are extracted. Spatially average reflectances are computed for each site and for each composite period if the number of good quality pixels on the mode composite day in the 5×5 window is larger than or equal to 15. VIs are calculated from the average reflectances.

2.3 ASRVN data

The ASRVN dataset over the 40 AERONET site, including 9 years (2000-2008) of MODIS TERRA data, is available as a standard MODIS product (MODASRVN), downloaded from the Level 1 and Atmosphere Archive and Distribution System website (<http://ladsweb.nascom.nasa.gov/data/search.html>). In this study, we assume that the ASRVN data set is accurate enough to be used as a reference to evaluate the quality of the MODIS 1 km 16-day composite VI product.

ASRVN IBRF bands 1-3 (red, NIR and blue) are extracted over 5×5 windows centered at the 40 AERONET sites. Due to cloud or unavailability of aerosol and water vapor data, IBEF data is missing for some ASRVN pixels. If the number of valid IBRF is equal to or greater than 15 in a 5×5 window, then the valid IBRF values are spatially averaged to get the average IBRF for the window, from which ASRVN VI values are calculated.

2.4 Comparison of ASRVN and MODIS VIs

Reflectance and VIs from the ASRVN and MOD13 dataset are compared at two temporal resolutions, i.e. 1-day and 16-day comparisons. In the 1-day comparison, MOD13 pixel composite DOY and year are extracted and the ASRVN VIs with the same date are compared with the corresponding MODIS VIs on the same site. Since the ASRVN and the MODIS data are collected on the same day, their view and sun geometries are identical. Thus, the difference between the two data sets in the 1-day comparison results from the differences in atmospheric correction of the two data sets. Therefore, the difference between the two data sets can be explained as the error of atmospheric correction in the MODIS VI product.

In the 16-day comparison, the MOD13 VIs are compared with the ASRVN nadir-adjusted VIs based on ASRVN daily VIs during the same MOD13 composite 16-day period. The difference between the two data sets in the 16-day comparison can be used to evaluate the overall MODIS VI uncertainties, including both the atmosphere and angular effects on the MODIS VIs.

3. RESULTS

3.1 Comparison of MOD13 with ASRVN (daily analysis)

The MOD13-ASRVN reflectance differences increased as the increase of the ASRVN reflectances, particularly for the blue band (Fig. 2). All of the MOD13 input reflectances were negatively biased in comparison with the ASRVN reflectance and the biases were -0.005, -0.003 and -0.007 for the red, NIR and blue reflectances, respectively (Fig. 2b). The standard deviation of the blue difference between the MOD13 and ASRVN was highest, followed by the similar standard deviations of the red and NIR differences. MAD between the MOD13 and ASRVN blue reflectance was 0.011, highest among the three reflectances, due to the largest bias and standard deviation of the blue difference. MAD of the red reflectance (0.007) was slightly larger than the NIR MAD (0.006) due to the relatively larger red bias. Thus the MOD13 NIR reflectance is most accurate and the blue reflectance has the largest error among the three reflectances.

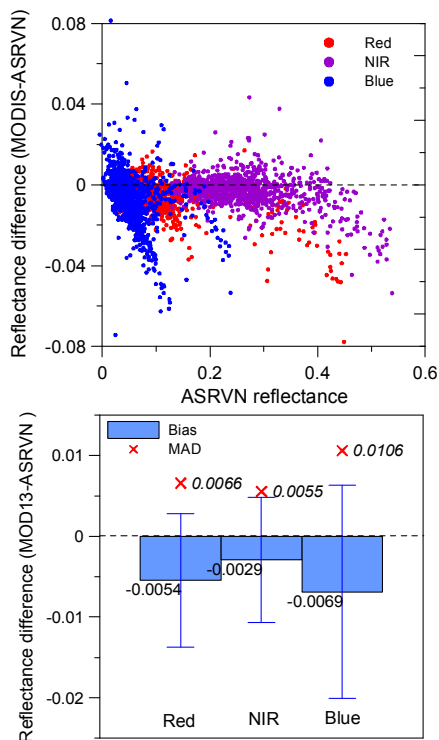


Fig. 2. Errors in MOD13A2 input reflectances in the 1-day comparison: (a) scatter of the MOD13A2-ASRVN reflectance difference, (b) mean, standard deviation and mean absolute difference (MAD) of the reflectance difference.

The MOD13 NDVI was positively biased in comparison with the ASRVN NDVI due to the negative bias of the red reflectance, so was the EVI2 (Fig. 3). However, the EVI bias was ignorable. The standard deviation of the NDVI difference was greater than those of the EVI and EVI2 and the NDVI MAD was 0.020, highest among the three VIs. The standard deviation of the EVI difference was larger than that of the EVI2 difference, but the EVI2 bias was larger than the EVI bias, resulting the similar EVI and EVI2 MAD. All of the three VI differences were relatively higher in the intermediate VI range than those in the low or high VI ranges (Fig. 3a). The mean error of the MODIS NDVI was two times of the MODIS EVI and EVI2 mean errors.

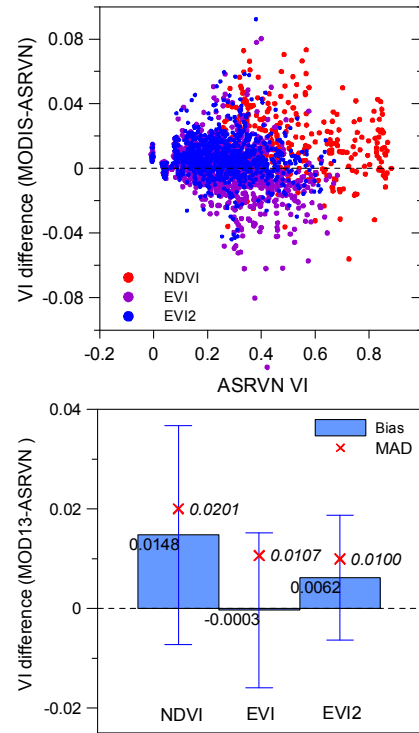


Fig. 3. Errors in MOD13A2 VI product in the 1-day comparison: (a) scatter of the MOD13A2-ASRVN VI difference, (b) mean, standard deviation and mean absolute difference (MAD) of the VI difference.

3.2 Comparison of MOD13A2 composite VIs with ASRVN nadir-adjusted VIs (16-day comparison)

The MOD13A2 16-day composite VIs are compared with the ASRVN nadir-adjusted VIs and the differences are shown in Fig. 4. All of the three MODIS VIs were positively biased. The NDVI bias was highest, 0.023, and the EVI bias was lowest, 0.002. MAD of NDVI was greatest, 0.026, whereas MAD values of EVI and EVI2 were very close, 0.015 and 0.0145, respectively.

The difference of MAD of the MODIS VIs in the 1-day and 16-day comparisons are shown in Fig. 5. MAD in the 16-day comparison indicates the overall error of the 16-day composite VIs, including error in atmospheric correction and the view zenith angle effects on VIs. VI errors in atmospheric correction account for the most of the error in the 16-day composite MODIS VIs. The view zenith angle effects made the VI errors increased by 0.006, 0.004 and 0.0045 for the MODIS NDVI, EV and EVI2, respectively, on average.

Overall, the uncertainties in the MODIS VI products are relatively low in both daily and composited products. Further work is needed to better understand the contributions of the red, NIR, and blue bands toward VI product uncertainties and for cross-sensor continuity assessments.

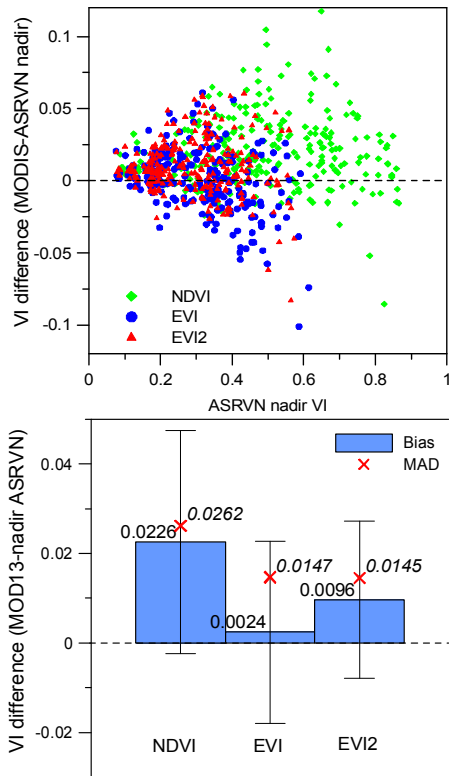


Fig. 4. Errors in the MOD13A2 VI product in the 16-day comparison: (a) scatter of the VI difference between MOD13A2 VIs and ASRVN nadir-adjusted VIs, (b) mean, standard deviation and mean absolute difference (MAD) of the 16-day VI difference.

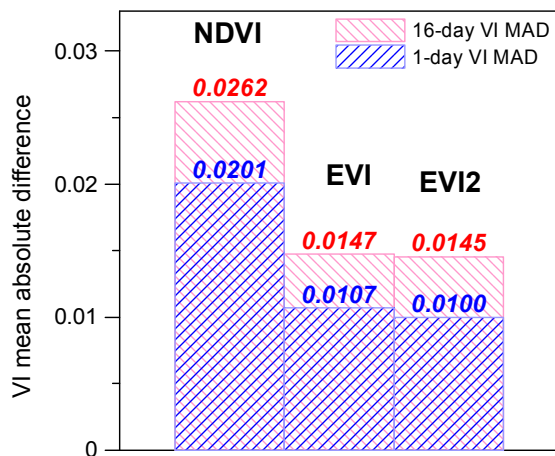


Fig. 5. Comparison of the Mean Absolute Difference (MAD) between MOD13A2 and ASRVN in the 1-day and 16-day comparisons.

Acknowledgements

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