IMPACT OF BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION ON MODIS VEGETATION INDICES IN SOUTHEAST ASIA TROPICAL FORESTS

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KEY WORDS: BRDF, SZA, EVI, NDVI

ABSTRACT: Tropical forests play important roles on global climate and biodiversity. The Moderate Resolution Imaging Spectroradiometer (MODIS), with high temporal resolution, provide a useful tool to study tropical forest dynamics, including seasonality and inter-annual variation. However, optical satellite data have cloud, aerosol and bidirectional reflectance distribution function (BRDF) effects, that create uncertainty in tropical forest studies. In the Amazon, some researchers demonstrated the difficulties in separating true forest dynamics from BRDF artefacts and seasonal cloud and aerosol influences. Lastly, optical reflectance saturation in dense tropical forests may restrict the retrieval of phenology information.

In this study, we investigated the impact of BRDF effects on MODIS vegetation indices (VI) in Southeast Asia (SEA) tropical forests, the least studied area compared to other major tropical forests (South America and Central Africa). Moreover, unlike Amazon tropical forests, VI seasonality in SEA forests is not synchronous with sun-sensor geometries. We used 10-year data of daily MODIS BRDF (MCD43A1) collection 6 product, a kernel-driven model product that allows us to retrieve VI values for a range of fixed solar zenith angles (SZA). We compared these with the standard VI products (MOD13A1, MYD13A1) to analyse BRDF influences. The results show significant BRDF effects in all forest sites. Generally, smaller SZA yielded higher VI signals in forests. We found tradeoff's between VI robustness to BRDF effects and saturation that impacted upon the retrievals of phenology parameters.

1. INTRODUCTION

Tropical forests play significant roles on global climate and biodiversity. They help stabilize the world's climate; provide a home to many plants and animals; and protect against flood, drought, and erosion. Understanding tropical forest phenology is critical because of recent climate change or extreme events.

Spaceborne optical sensors provide a global perspective on studying seasonal and interannual changes in vegetation phenology by capturing landscape reflectance. However, optical satellite sensors usually have critical issues of clouds, aerosols and BRDF effects, especially in tropical forests due to the variation of atmospheric conditions with aerosol contamination from fires in dry seasons and clouds in wet seasons. That is why it's hard to extract the annual profile of tropical forest dynamics with low temporal resolution satellites, such as Landsat. The Moderate Resolution Imaging Spectroradiometer (MODIS), launched in 1999, generates daily global scenes and provides 16-day composited vegetation indices (VI). VIs are spectral transformations of two or more bands that offer useful tools to study tropical forest dynamics, including seasonality and inter-annual variation.

Pinter et al. (1978) suggested that a perfect time-series of spectral vegetation index should maintain maximum sensitivity to real landscape characteristics while being relatively unaffected by solar angles, atmospheric turbidity, topography and view angles. But MODIS, like other space observation instruments, often acquires images over a wide range of sensor and solar geometric configurations. Sun-sensor geometry artefacts could raise controversial results among scientists. One important controversy was whether Amazon rainforest green-up during dry seasons (Huete et al. 2006, Morton et al. 2014, Saleska et al. 2016). Consequently, BRDF correcting optical remote sensing data is essential to extract the actual response of vegetation, and to improve the monitoring of vegetation dynamics and productivity from satellites.

In this article, we investigated mainland Southeast Asia because this is the least studied area compared to Amazon or Central Africa forests. Moreover, Indochina forests contain both tropical rainforests and dry forests. Many researchers focus on rainforests, while dry forests comprise slightly less than half of subtropical and tropical forests (Murphy and Lugo 1986). In mainland Southeast Asia, 30% of forests are classified as dry forests (Poffenberger 2000). Because of mixing impact between sun-sensor geometries and forest phenology, it is difficult to extract the true forest phenology profiles over mainland Southeast Asia. There is thus a need to have more studies conducted in Indochina forests to understand the effects of sun-sensor geometries over different, dry tropical to wet forest types.

The primary purpose of this study is to gain a better understanding of sun-angle influences on time-series vegetation indices of Southeast Asia tropical forests for improving monitoring of forest dynamics. Specifically, the objectives of this study are: (1) Simulate time-series of NDVI and EVI with different SZA at multiple forest sites; (2) Understand the SZA impact on NDVI and EVI time-series; and (3) Assess NDVI and EVI capabilities in capturing SEA forest phenology, both terms of robustness to BRDF effect and saturation.

2. METHODOLOGY

2.1. Study sites

Forests of SEA are endangered and threatened by human activities (Blackie, et al. 2014). In this study, we only focus on influences of sun-sensor geometries on MODIS VIs in mainland SEA tropical forests and correct the other factors. We selected undisturbed forest areas to avoid any complications of human impact on forest phenology. Hansen et al. (2013) introduced the first global forest cover change map between 2000 and 2013 using a combination of MODIS and Landsat data. Later, pan-tropical hinterland forest extent, derived from the Hansen product, was mapped by Tyukavina (2016). We used these selected four sites based on variations in latitudinal SZA seasonal changes. The locations of the chosen sites are shown in the following table and figure.

Table 1 Location of selected sites with latitude ranging from north to south (27.27 down to 5.82)

No	Latitude	Longitude
1	27.27	96.76
3	20.500	96.438
4	12.65	99.36
5	5.82	101.29

Figure 1 Position of selected sites (using Google based map)

2.2. Vegetation Indices

NDVI and EVI are widely used to represent canopy “greenness”. NDVI has been used for over 40 years and is one of the most successful VIs, however, it has certain disadvantages to study vegetation in tropical areas, which have high variation of atmospheric conditions with aerosols and clouds. Moreover, NDVI can reach saturation in dense vegetation canopies (Xiao, 2009).

EVI is an ‘optimized’ vegetation index with suitable characteristics to potentially overcome NDVI weaknesses in studying tropical forests, including improved sensitivity in high biomass regions and reducing atmospheric effects and soil background (Huete et al., 2002).

The equations of NDVI and EVI are:

$$NDVI = \frac{NIR-Red}{NIR+Red} \tag{1}$$

$$EVI = 2.5 * \frac{NIR-Red}{NIR+6*Red-7.5*Blue+1} \tag{2}$$

Where NIR, Red and Blue are surface reflectance of equivalent bands.

2.3. Datasets

Firstly, we decided to choose MOD13A1 and MYD13A1 because they are datasets which many researchers would use when they need MODIS VIs at 500m resolution. Moreover, MODIS has two satellites, Terra which captures daily landscapes at 10:30 am and Aqua which generates images at 1:30 pm and it is worth to explore whether there are differences between Terra and Aqua VI. Furthermore, six years (January 2010 to December 2015) of 16-day Vegetation Index product (MOD13A1/MYD13A1) were obtained and then NDVI, EVI and SZA were extracted for each forest site.

To avoid sun-sensor geometry influences on VIs, we used a semi-empirical BRDF model to simulate fixed sun-sensor MODIS surface reflectance. The theoretical basis of the model is that the land surface reflectance can be modeled as a sum of three kernels representing basic scattering types: isotropic, volume and surface scattering (Schaaf et al., 2002; 2011). Those scattering parameters are storing in MCD43A1 at 500m pixel resolution and could generate fixed-SZA VIs by implementing RossThick-LiSparse kernel functions (Strahler et al. 1999). The latest version (collection 6) of MCD43A1 is daily retrieved data and represent the best BRDF data based on 16-day of inputs from both Terra and Aqua MODIS. All MODIS data are available at Reverb EOSDIS (https://reverb.echo.nasa.gov)

2.4. Research methods

From the derived MODIS data, including MODIS Terra/Aqua/BRDF, we applied QA filtering by using MODIS QA flags to remove poor values. Still, we chose "marginal" (Didan et al. 2015) over "good" QA levels because of the lack of data availability. On the other hand, we selected "marginal" QA to balance between quality and availability.

While VI values could be retrieved directly from standard Vegetation Index products (MOD13A1 and MYD13A1), sun-sensor angle information needs to be given to MODIS MCD43A1 product to generate surface reflectance and then vegetation indices (NDVI or EVI). To investigate the sensitivity of NDVI and EVI to sun-angle at any given date, VIs were fixed at four sun-angles (all nadir view) ranging from 0 to 45 degree (VI_{sz0}, VI_{sz15}, VI_{sz30}, VI_{sz45}) and calculated. We selected those fixed angles since the magnitudes of SZA seasonal changes (Fig.2) exhibited that higher latitudes came with greater SZA range of seasonal variations, with SZA ranging from about 22-35 degree at latitude 5.82 and 17-53 degree at latitude 27.27. Moreover, solar zenith elevation peaks at two times a year in locations near the equator, which can be clearly seen at latitude 5.82 SZA annual variation.

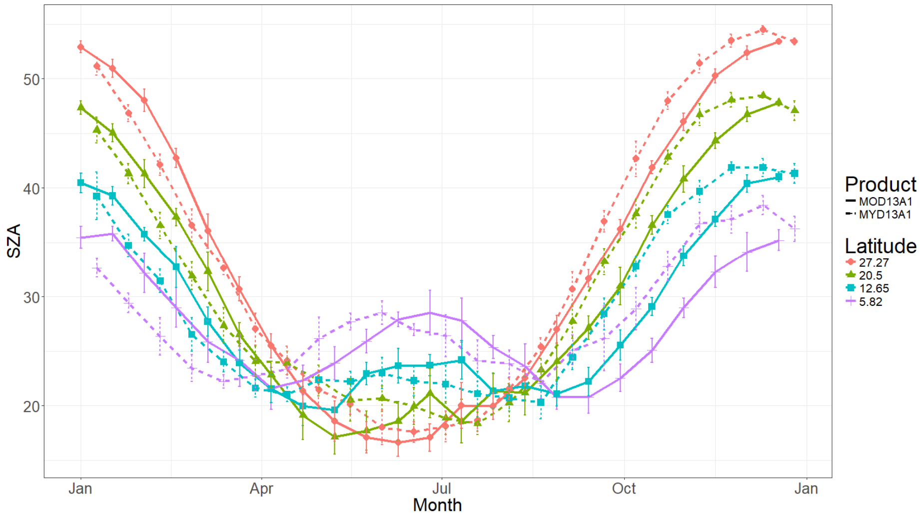

Figure 2. Annual Solar Zenith Angle (SZA) variation of 4 sites based on their latitudes (for MODIS Aqua and Terra satellite overpass times; 10:30am and 1:30pm local time).

Because we selected undisturbed forest sites, we assumed that each forest is a homogenous area and its phenology is the same in the whole coverage. So we averaged MODIS data for each forest to get a single time-series of each band or VI. After that, VI time-series were smoothed by Savitz-Golay algorithm (Savitzky et al. 1964) because the filter increase signal-to-noise ratio without greatly distorting the signal (Jönsson & Eklundh, 2004). Then we used those processed data to create annual time-series which used to analyze the impact of SZA to VI values or derived information like phenological parameters. Meaningful phenology information is extracted by identifying appropriate phenological parameters. They are derived metrics from VI time-series to represent vegetation growing stage through key transition dates such as green up, maturity, or senescence. In this paper, we investigated start of growing season (SGS) parameter. SGS was defined as when EVI reach the value equals to the minimum value prior to the growing season plus 10% of seasonal amplitude (gaps between minimum and maximum value) during the greenup phase (Ma et al., 2013).

3. RESULTS AND DISCUSSION

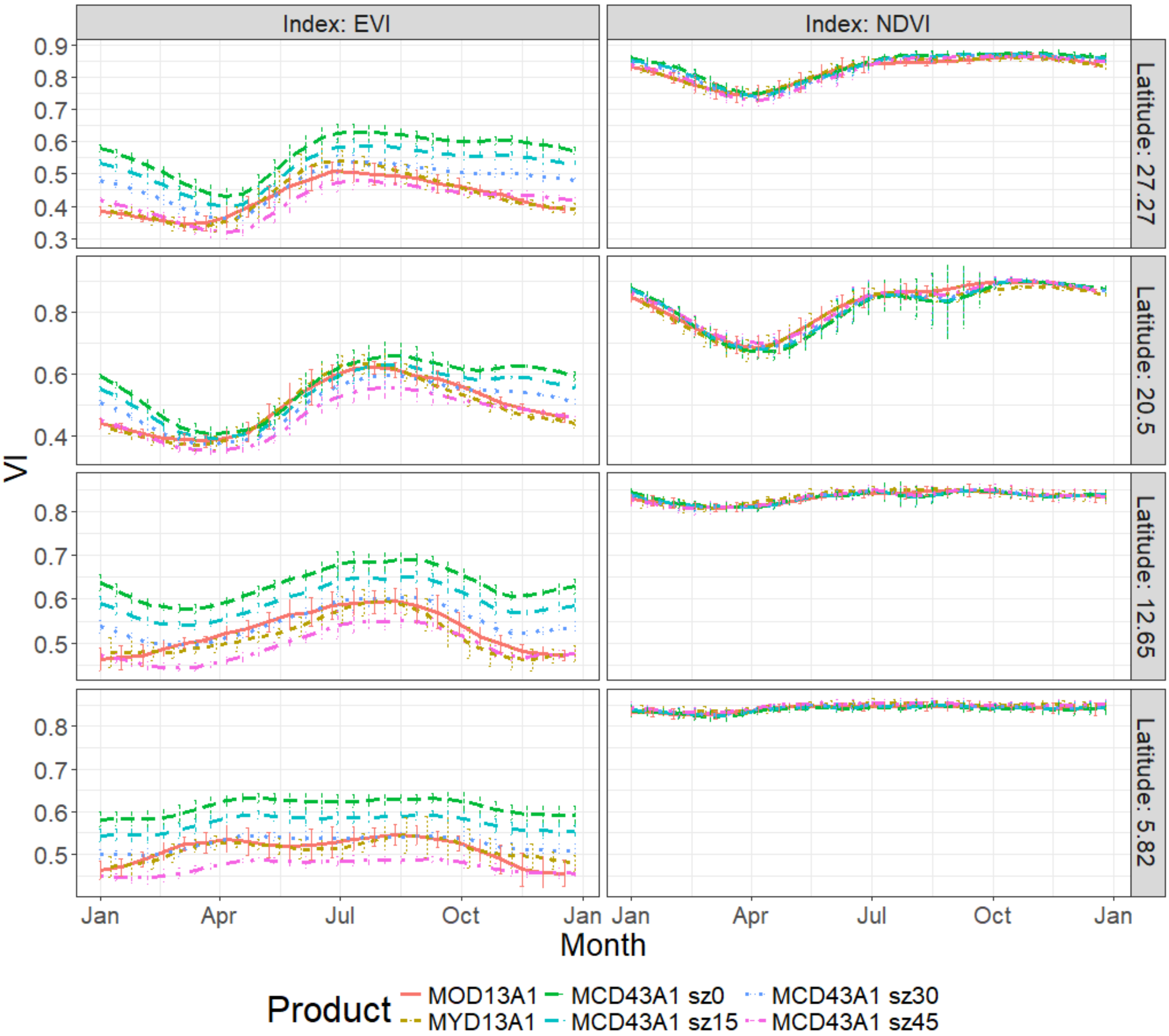

Figure 3 Seasonal NDVI and EVI of all 4 forest sites

Figure 3 shows the seasonal time-series of NDVI and EVI products from the standard MODIS Terra/Aqua satellites with various sun-angle configurations. It is apparent that NDVI is robust to SZA configurations because all NDVI patterns are similar and variations across the various products are minor compared to the variations seen with EVI. On the other hand, EVI was more affected by SZA. In general, lower SZAs yielded higher VI signals in all forest sites, and influences of SZA increased with higher EVI values.

Nevertheless, NDVI is not suitable to study tropical forests, at least in mainland SEA forests because of saturation issues, as expressed in Figure 3. NDVI seems to reach its saturation point around 0.8 - 0.85 and hardly increases after its saturation threshold. Consequently, the seasonal magnitude of forest NDVI is quite small and it is troublesome to extract phenological metrics from annual NDVI time-series data. For example, at site 4 (latitude 5.82), seasonal EVI displays distinct seasonal signals while NDVI retained a high value (over 0.8) for the whole year. Therefore, EVI is more suitable than NDVI to monitor "greenness" of Southeast Asia tropical forests despite NDVI robustness to sun-sensor geometries. This suggests that the NDVI robustness is aided by signal saturation. Accordingly, we only used EVI in the remaining analyses.

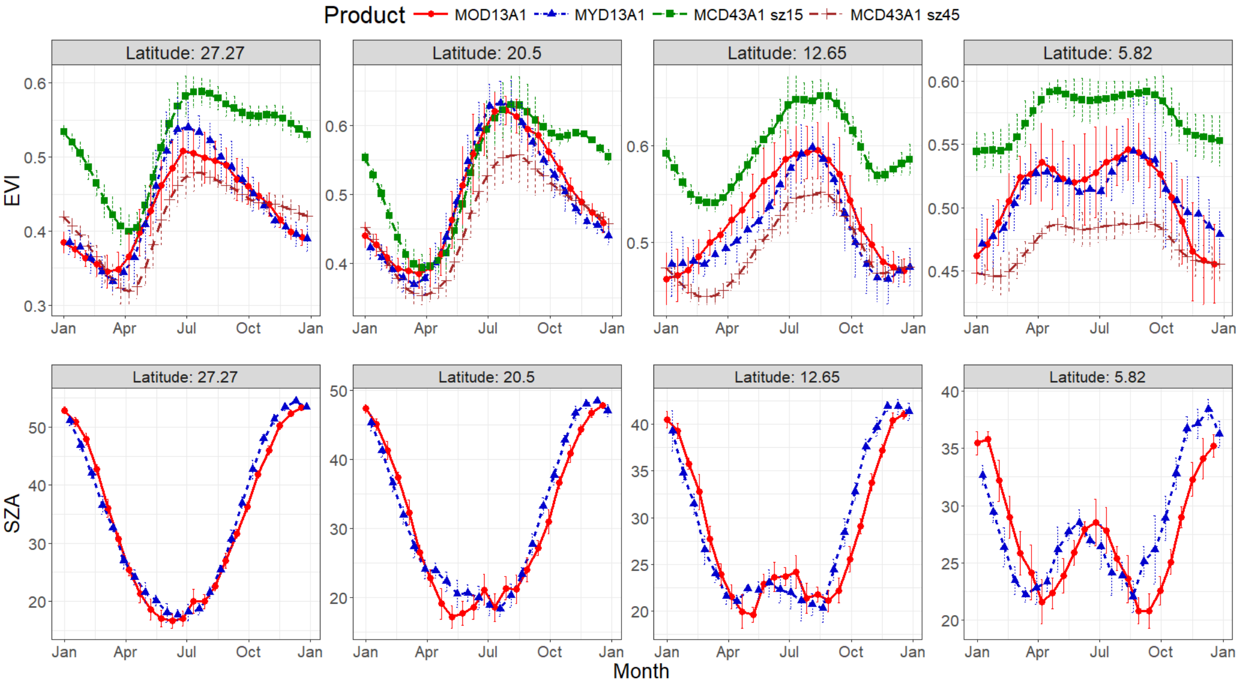

Figure 4 Seasonal EVI incorporating with SZA

Figure 4 demonstrates the seasonal time-series of EVI incorporating with MODIS Terra and Aqua SZAs. Because of similar patterns among fixed-SZA EVI (EVIsz0, EVIsz15, EVIsz30, EVIsz45), we used EVIsz15 and EVIsz45 to compare with MODIS Terra and Aqua EVI. And results (Fig.4) shows that differences between fixed-SZA and standard (varying SZA) EVI resulted in considerable differences in both shape and magnitude. Standard EVI tended to match with lower fixed-SZA EVI (EVIsz45) while SZA were high and reversed with lower SZA. However, the matching is varied depended on SZA values. Terra and Aqua EVI value approximately equals to EVIsz45 while SZA is around 45 degrees. It means that BRDF model is accuracy in this case and it confirms impact of sun-sensor geometries to standard EVI. However, standard EVI and EVI_{sz15} lines do not intersect around 15-20 degrees of SZA, except site 2. Imperfection of BRDF model or cloud issue of wet season are potential causes of imprecision. Another noteworthy evidence of sun-angle impacts to EVI is seen from April-to-September EVI values of site 4. Terra and Aqua EVI of that period shows correlation between EVI and sun-angle: lower SZA generates higher EVI; while fixed-SZA EVI was stable over the same period.

Considerable differences in both EVI pattern and magnitude resulted in differences in extracting phenological parameters. One example of an important finding is in obtaining start of growing season (SGS) of forest sites (Table 2). The SGS derived from standard EVI usually occurred earlier than SGS derived from fixed sun-angle EVI, except at site 2, which was approximately around the same period. SGS shifting ranged from 10 days (site 1) up to two or three months (site 3). Because the onset of summer rainy season in mainland Southeast Asia begins in late April to early May due to influence of "southeast" monsoon, shifting of SGS might lead to controversary in case researchers use standard EVI to generate SGS information.

Table 2. Day of year (DOY) of start of growing season (SGS)

No	Latitude	MOD13A1 SGS (DOY)	MYD13A1 SGS (DOY)	MCD43A1 SZ45 SGS (DOY)
1	27.27	97 (7/4)	105 (15/4)	115 (25/4)
2	20.500	114 (23/4)	105 (15/4)	110 (20/4)
3	12.65	49 (18/2)	9 (9/1)	89 (30/3)
4	5.82	17 (17/1)	25 (25/1)	45 (14/2)

In summary, our results showed that EVI was highly sensitivity to SZA but is more suitable than NDVI, which was nearly unaffected by sun-angle – due to saturation, to study tropical forest phenology in Southeast Asia. However, we found that the impact of SZA varied based on forest latitude locations due to annual SZA variations and SZA influences could alter phenological parameters based on our SGS testing. Further studies are needed to improve our understanding of sun-angle effect on vegetation indices because of uncertainty of BRDF model in wet seasons and only one phenological parameter was investigated.

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