International Journal of Applied Earth Observation and Geoinformation 35 (2015) 294–304

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Spectral anisotropy of subtropical deciduous forest using MISR and MODIS data acquired under large seasonal variation in solar zenith angle

Fábio Marcelo Breunig[a,*], Lênio Soares Galvão[b], João Roberto dos Santos[b], Anatoly A. Gitelson[c], Yhasmin Mendes de Moura[b], Thiago Sousa Teles[b], William Gaida[a]

[a] Universidade Federal de Santa Maria (UFSM), Departamento de Engenharia Florestal, linha Sete de Setembro s/n, sala 59, bloco de apoio 4, CESNORS/UFSM, 98400-000 Frederico Westphalen, RS, Brazil
[b] Instituto Nacional de Pesquisas Espaciais (INPE), Divisão de Sensoriamento Remoto, Caixa Postal 515, Av. dos Astronautas, 1758, Bairro Jardim da Granja, 12245-970 São José dos Campos, SP, Brazil
[c] School of Natural Resources – University of Nebraska, Lincoln 303 Hardin Hall 3310 Holdrege Street, Lincoln, NE 68583-0973, United States

ARTICLE INFO

Article history:
Received 19 June 2014
Accepted 23 September 2014
Available online 15 October 2014

Keywords:
MISR
MODIS
View-illumination geometry
NDVI
EVI
PROSAIL

ABSTRACT

Recent studies in Amazonian tropical evergreen forests using the Multi-angle Imaging SpectroRadiometer (MISR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) have highlighted the importance of considering the view-illumination geometry in satellite data analysis. However, contrary to the observed for evergreen forests, bidirectional effects have not been evaluated in Brazilian subtropical deciduous forests. In this study, we used MISR data to characterize the reflectance and vegetation index anisotropies in subtropical deciduous forest from south Brazil under large seasonal solar zenith angle (SZA) variation and decreasing leaf area index (LAI) from the summer to winter. MODIS data were used to observe seasonal changes in the normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI). Topographic effects on their determination were inspected by dividing data from the summer to winter and projecting results over a digital elevation model (DEM). By using the PROSAIL, we investigated the relative contribution of LAI and SZA to vegetation indices (VI) of deciduous forest. We also simulated and compared the MISR NDVI and EVI response of subtropical deciduous and tropical evergreen forests as a function of the large seasonal SZA amplitude of 33°. Results showed that the MODIS-MISR NDVI and EVI presented higher values in the summer and lower ones in the winter with decreasing LAI and increasing SZA or greater amounts of canopy shadows viewed by the sensors. In the winter, NDVI reduced local topographic effects due to the red-near infrared (NIR) band normalization. However, the contrary was observed for the three-band EVI that enhanced local variations in shaded and sunlit surfaces due to its strong dependence on the NIR band response. The reflectance anisotropy of the MISR bands increased from the summer to winter and was stronger in the backscattering direction at large view zenith angles (VZA). EVI was much more anisotropic than NDVI and the anisotropy increased from the summer to winter. It also increased from the forward scatter to the backscattering direction with the predominance of sunlit canopy components viewed by MISR, especially at large VZA. Modeling PROSAIL results confirmed the stronger anisotropy of EVI than NDVI for the subtropical deciduous and tropical evergreen forests. PROSAIL showed that LAI and SZA are coupled factors to decrease seasonally the VIs of deciduous forest with the first one having greater importance than the latter. However, PROSAIL seasonal variations in VIs were much smaller than those observed with MODIS data probably because the effects of shadows in heterogeneous canopy structures or/and cast by emergent trees and from local topography were not modeled.

* Corresponding author. Tel.: +55 5596405988.
E-mail addresses: fabiobreunig@gmail.com, fabiobreunig@yahoo.com.br (F.M. Breunig).

http://dx.doi.org/10.1016/j.jag.2014.09.017
0303-2434/

Introduction

Recent studies in Amazonian tropical evergreen forests have demonstrated the importance of considering the geometry of data acquisition and correcting for bidirectional effects when analyzing time series of the Moderate Resolution Imaging Spectroradiometer (MODIS)/Terra (Galvão et al., 2011; Morton et al., 2014). View-illumination geometry contributes to explain controversial findings reported in the literature on the dry season and drought sensitivity of tropical forests from the use of the MODIS enhanced vegetation index (EVI) (e.g. Huete et al., 2006; Saleska et al., 2007; Asner and Alencar, 2010; Samanta et al., 2010; Atkinson et al., 2011; Xu et al., 2011). Even choosing the MODIS 16-day composite product to reduce the atmospheric and angular influences, directional and view angle effects are still significant because they impact differently on VIs (Verrelst et al., 2008; Sims et al., 2011; Breunig et al., 2011; Galvão et al., 2013).

The anisotropic behavior of Amazonian evergreen forests has been also studied with the Multi-angle Imaging SpectroRadiometer (MISR)/Terra (Moura et al., 2012). MISR provides a unique opportunity to characterize the angular and directional spectral response of vegetation in four bands (visible and near infrared), nine view angles and two view directions (backscattering and forward scattering) (Diner et al., 1998). Differently from MODIS, in which the selected pixels in the composite products come from different dates, view angles and view directions, MISR acquires quasi-simultaneous along-track multi-angular data with 1.1-km spatial resolution. Thus, this instrument is adequate to study the angular behavior over different vegetation types of the most frequently used VIs like the EVI (Huete et al., 2002) and the normalized difference vegetation index (NDVI) (Rouse et al., 1973).

Contrary to the observed for evergreen forests, MODIS and MISR were not used to study the anisotropy of Brazilian subtropical deciduous forests, which comprise a very distinct scenario from the Amazon in several aspects. For example, in Amazonian evergreen forests, nadir-viewing MODIS and MISR EVI increases from the beginning to end of the dry season with decreasing solar zenith angle (SZA) due to the strong dependence of this index to the near infrared (NIR) reflectance (Galvão et al., 2011; Moura et al., 2012). The reduced amounts of canopy shadows viewed by the sensor toward the end of the dry season produce an increase in the NIR reflectance as well as in the EVI, which is not associated with canopy photosynthetic activity. Such effect is stronger in transitional forests from south Amazon because of the large seasonal SZA amplitude (close to 18°) observed with increasing latitudes.

By contrast, in Brazilian subtropical deciduous forests located in south Brazil at middle latitudes, there are two well-defined seasons defined by temperature instead of precipitation. The seasonal SZA amplitude is much larger (>30°) than in the Amazon. However, the solar illumination effect is coupled with that from the decreasing LAI from the summer (December–March) to winter (June–September). Furthermore, as the Sun angle changes with the seasons, it can be anticipated that the phenological response of the deciduous forest will be affected in some extent by the amount of shadows cast in the canopies and by the local topography that modifies the amount of incoming solar radiation and the reflected solar radiation to the satellite (Song and Woodcock, 2003). In rough terrains, topographic effects affect differently the VIs (Matsushita et al., 2007). Their detection depends also on the spatial resolution of the sensors to hidden (pixel aggregation from low spatial resolution) or highlight (high spatial resolution) changes in orientation from horizontal to inclined surfaces and the associated modifications in the amounts of energy reflected toward the sensors.

Thus, subtropical deciduous forests of south Brazil comprise an interesting case study. They may improve the knowledge on the view-illumination influence on vegetation indices (VIs) calculated in other regions like the Amazon using large field-of-view (FOV) or multi-angular instruments. Investigation of the spectral anisotropy of this type of forest may contribute for a better comprehension of the bidirectional effects on VIs determination in other environments.

In this study, we use MISR data to characterize the anisotropy of the reflectance and vegetation indices (NDVI and EVI) in subtropical deciduous forest from the Brazilian *Parque Estadual do Turvo* (PET) under large seasonal SZA variation and with decreasing LAI from the summer to winter. MODIS data are analyzed to detect seasonal changes in VIs and LAI and inspect topographic effects on their determination. Field/laboratory measures of chlorophyll and MODIS LAI estimates are used as inputs for PROSAIL radiative transfer modeling (Jacquemoud et al., 2009). The objective was to simulate the NDVI and EVI response of deciduous and evergreen forests, as a function of the large seasonal amplitude of SZA, and to analyze the relative contribution of LAI and SZA to the seasonal decrease of VIs.

Study area

Created in 1947, the *Parque Estadual do Turvo* (PET) is located in the Brazilian state of *Rio Grande do Sul* and has one of the largest fragments of subtropical deciduous forest from south Brazil (Fig. 1). The PET is mainly composed of mature forest with a few occurrences of very small areas of secondary forests in the southwestern limit of the park and close to the Uruguay River due to old human-induced activities (Guadagnin, 1994; Ruschel et al., 2007). With 17,491 hectares, the PET is an extension of the Forest of Misiones in Argentina (10,000 km^2) having high biodiversity (Brack et al., 1985; SEMA, 2005; Guadagnin, 1994; Leite, 2002; Bulfe, 2008).

According to the Köppen classification, the climate is humid subtropical (Cfa). Monthly accumulated precipitation, averaged between 2000 and 2012, is regularly distributed across months without a well-defined dry season, as indicated by data obtained from the closest rain gauge from the park in the municipality of Iraí (Fig. 2). On the other hand, there are two seasons defined by temperature with the first one (higher temperatures) from November to March and the other (lower temperatures) from May to September (Rosa et al., 2013). Measurements showed the highest mean temperature (2000–2012) in January (25 °C) and the lowest one in July (13 °C) (Fig. 2). The accumulated annual rainfall generally reaches 1600 mm (SEMA, 2005). The variation in altitude ranges from 100 to 450 m with an average value of 300 m, as also illustrated by the Advanced Spaceborne Thermal Emission and Reflection Radiometer – Global Digital Elevation Map (ASTER–GDEM) (Fig. 1). The topography is gently undulated in the highest portions of the park with high slopes (rough terrains) in the lowest portions near the major rivers.

The predominant vegetation type is seasonal deciduous forest and is part of the Atlantic Forest biome (IBGE, 2012). In the absence of a well-defined dry season, more than 50% of the upper stratum species lost their leaves in some extent in the winter. It occurs due to the low temperatures in the winter that difficulty water absorption by the roots producing a hydric deficit even with the availability of water in the soil horizons (Veloso et al., 1991; Franco, 2008). Some trees may be partially or completely involved by lianas. Previous floristic inventories reported in the literature have shown dozens of families and species in the PET (Brack et al., 1985; Dias et al., 1992; Vasconcelos et al., 1992). In September 2013, our floristic survey in eastern PET (14 sample plots of 20 m × 50 m), over trees with diameter at the breast height (DBH) greater than 10 cm, identified 31 botanical families, 65 genera and 74 species. The following species with the highest importance value index were identified: *Syagrus romanzoffian* (Cham.), *Nectandra megapotamica* (Spreng.),