Agricultural and Forest Meteorology 246 (2017) 218–230

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Evaluation of four long time-series global leaf area index products

Zhiqiang Xiao[a,*], Shunlin Liang[a,b], Bo Jiang[a]

[a] State Key Laboratory of Remote Sensing Science, Beijing Normal University, Beijing, 100875, China
[b] Department of Geographical Sciences, University of Maryland, College Park, MD, 20742, USA

ARTICLE INFO

Keywords:
AVHRR
GIMMS3g
GLASS
NCEI
GLOBMAP
LAI
MODIS
Inter-comparison

ABSTRACT

As an important vegetation biophysical variable, leaf area index (LAI) is a critical input parameter in many climate and ecological models. There exist four long time-series global LAI products since the 1980s, namely GLASS AVHRR, NCEI AVHRR, GIMMS3g and GLOBMAP. Currently, no inter-comparison studies exist to evaluate these LAI products and understand their differences for effective applications. In this study, the four long time-series global LAI products were inter-compared to evaluate their temporal and spatial discrepancies. These LAI products were also compared with MODIS LAI product and LAI values derived from high-resolution reference maps at VAlidation of Land European Remote sensing Instruments (VALERI) sites. The results show that the GLASS AVHRR and GLOBMAP LAI products are spatially complete, but the NCEI AVHRR and GIMMS3g LAI products contain many missing pixels, especially in rainforest regions. These LAI products reasonably represent the global vegetation characteristics and their seasonal variability. A relatively large discrepancy among these LAI products was observed in tropical forest regions, where the GLASS AVHRR and NCEI AVHRR LAI values achieved good agreement with the MODIS LAI values, but were between 0.5 and 1.0 LAI units lower than the GLOBMAP LAI values and higher than the GIMMS3g LAI values (more than 0.5 LAI units). Over the last three decades, the GLASS AVHRR, NCEI AVHRR, GIMMS3g LAI products show increasing trends for all biome types except evergreen needleleaf forests and deciduous needleleaf forests, but the GLOBMAP LAI product shows positive trends only for the grasses/cereal crops and shrubs. A comparison of these LAI products against the LAI values derived from high-resolution reference maps demonstrated that the GLASS AVHRR LAI values provided the better performance (RMSE = 0.9014 and Bias = −0.1885) than the NCEI AVHRR LAI values (RMSE = 1.0459 and Bias = −0.5695), the GIMMS3g LAI values (RMSE = 1.0971 and Bias = −0.3904) and the GLOBMAP LAI values (RMSE = 1.6145 and Bias = −0.9414).

1. Introduction

Leaf area index (LAI) is an important vegetation biophysical variable that has been widely used for crop-growth monitoring and yield estimation, land-surface process simulation, and global change studies (Bellucci et al., 2015; Myneni et al., 2002; Piao et al., 2015; Zhu et al., 2016). The estimation of LAI from remote sensing data is the only feasible way to generate LAI products at the regional and global scales.

Many algorithms have been developed to retrieve LAI from satellite remote sensing data (Liang, 2007; Fang et al., 2013), and multiple global LAI products have been produced from data acquired by the Advanced Very High Resolution Radiometer (AVHRR) (Claverie et al., 2016; Masson et al., 2003; Sellers et al., 1996; Xiao et al., 2016; Zhu et al., 2013), the Moderate Resolution Imaging Spectroradiometer (MODIS) (Knyazikhin et al., 1998; Myneni et al., 2002; Xiao et al., 2014), VEGETATION (Baret et al., 2007; Baret et al., 2013; Deng et al., 2006), Multiangle Imaging SpectroRadiometer (MISR) (Hu et al., 2003), POLDER (Roujean and Lacaze, 2002) and MEdium Resolution Imaging Spectrometer (MERIS) (Bacour et al., 2006).

It is important to evaluate these LAI products and understand their differences for effective applications. Currently, many studies have evaluated the temporal and spatial consistencies of these global LAI products through product inter-comparisons (Camacho et al., 2013; Garrigues et al., 2008; Weiss et al., 2007). The global LAI products were also validated by direct comparison with ground-based measurements (Abuelgasim et al., 2006; Cohen et al., 2006; Fang et al., 2012; Garrigues et al., 2008; Pisek and Chen, 2007; Yang et al., 2006) or lidar-derived LAI values (Jensen et al., 2011; Tang et al., 2014). These validation activities were restricted to specific products (Fensholt et al., 2004; Privette et al., 2002; Sea et al., 2011; Tian et al., 2004; Wang et al., 2005; Yang et al., 2006), different vegetation types (Claverie et al., 2013; De Kauwe et al., 2011; Serbin et al., 2013; Wang et al., 2005; Wang et al., 2004) and/or different spatio-temporal domains (Abuelgasim et al., 2006; Claverie et al., 2013; Privette et al., 2002).

* Corresponding author.
E-mail address: zhqxiao@bnu.edu.cn (Z. Xiao).

http://dx.doi.org/10.1016/j.agrformet.2017.06.016
Received 11 January 2017; Received in revised form 16 May 2017; Accepted 28 June 2017
Available online 11 July 2017

Among the existing global LAI products, the CYCLOPES and MODIS LAI products have been the most widely validated. The CYCLOPES LAI product rarely produces LAI values larger than 4.0 LAI units, which is mainly regarding an early saturation of the LAI product (Weiss et al., 2007). The MODIS LAI product displayed noisy temporal retrievals and unrealistically strong temporal variability, especially during growing seasons in some regions (Camacho et al., 2013; Garrigues et al., 2008; Xiao et al., 2014). The first version of the Geoland2 (GEOV1) LAI product and the Global LAnd Surface Satellite (GLASS) LAI product derived from MODIS surface reflectance data are global LAI products released in recent years. The few comparisons and validations of these LAI products performed to date demonstrated that the GEOV1 LAI values were clearly lower than the GLASS and MODIS LAI values in tropical forest regions, especially in January (Camacho et al., 2013; Xiao et al., 2016). The temporal smoothness of the GLASS LAI product was superior to that of the GEOV1 and MODIS LAI products, and the GLASS LAI values were in better agreement with ground-based LAI measurements than the GEOV1 and MODIS LAI values (Xiao et al., 2016). In general, the existing validation and inter-comparison of these global LAI products are currently limited to LAI products retrieved from MODIS, VEGETATION and other sensor data after 2000.

In order to meet the needs of many applications, such as land-surface process simulation, and global change studies, four long time-series global LAI products since the 1980s were generated. They are the third-generation Global Inventory Monitoring and Modeling System (GIMMS3g) (Zhu et al., 2013), GLASS AVHRR (Xiao et al., 2016), National Centers for Environmental Information (NCEI) AVHRR (Claverie et al., 2016) LAI products derived from AVHRR data and the Long-term Global Mapping (GLOBMAP) LAI product derived from AVHRR and MODIS data (Liu et al., 2012).

Currently, many researchers have used these long time-series global LAI products to analyze the response of vegetation to the changing environment. Zhu et al. (2016) investigated trends of LAI and their drivers for the period 1982–2009 using the GIMMS3g, GLASS and GLOBMAP LAI products and outputs from ten ecosystem models run at global extent. Piao et al. (2015) used the GIMMS3g, GLASS and GLOBMAP LAI products and outputs from five different process-based ecosystem models to detect and attribute a greening trend in China over the last three decades.

However, no inter-comparison studies of these long time-series global LAI products exist to evaluate these LAI products and understand their differences until now. In this study, the four long time-series global LAI products are inter-compared to evaluate their temporal and spatial discrepancies. These LAI products are also compared with MODIS LAI product and the LAI values derived from high-resolution reference maps.

The organization of this paper is as follows. Section 2 introduces the GLASS AVHRR, NCEI AVHRR, GIMMS3g and GLOBMAP LAI products. The MODIS LAI product and the high-resolution reference LAI maps used in this study are also described in this section. The methods used to evaluate these LAI products are described in Section 3. The spatial and temporal consistency analysis among the GLASS AVHRR, NCEI AVHRR, GIMMS3g and GLOBMAP LAI products and a comparison of these LAI products with MODIS LAI product and the LAI values derived from high-resolution reference maps are presented in Section 4. Conclusions are drawn in the final section.

2. Data

2.1. Global LAI products

2.1.1. GLASS LAI product

The GLASS LAI product is one of the GLASS product suite (Liang et al., 2013a,b), which was generated and released by the Center for Global Change Data Processing and Analysis of Beijing Normal University. It has a temporal resolution of eight days. The GLASS LAI product includes LAI retrievals derived from MODIS surface-reflectance data (denoted by GLASS MODIS) and LAI retrievals generated from the Long-Term Data Record (LTDR) AVHRR reflectance data (denoted by GLASS AVHRR). The GLASS MODIS LAI product is provided in a sinusoidal projection at a spatial resolution of 1 km and spans from 2000 to 2015, while the GLASS AVHRR LAI product from the latest version is provided in a geographic latitude/longitude projection at a spatial resolution of 0.05° (approximately 5 km at the Equator) and spans from 1981 to 2015.

The GLASS AVHRR LAI product was generated using general regression neural networks (GRNNs). The fused LAI values from the CYCLOPES and MODIS LAI products were aggregated to 0.05° spatial resolution using the spatial-average method. Then, the aggregated LAI time-series values and the corresponding reprocessed AVHRR reflectance values of the BELMANIP (Benchmark Land Multisite Analysis and Inter-comparison of Products) sites for 2003 and 2004 were used to train GRNNs (Xiao et al., 2016). Unlike existing neural network methods that use remote-sensing data acquired only at a specific time to retrieve LAI, the reprocessed AVHRR reflectance values from an entire year were inputted to the GRNNs to estimate the one-year LAI profiles. The GLASS AVHRR LAI product from the latest version, generated from the version 4 LTDR AVHRR reflectance data, was used in this study.

2.1.2. NCEI AVHRR LAI product

The NCEI AVHRR LAI product is distributed by the National Oceanic and Atmospheric Administration's (NOAA) NCEI (Claverie et al., 2014). The product offers daily temporal resolution and a 0.05° (~5 km) spatial resolution, which spans from 1982 to 10 days from present (Claverie et al., 2016). The NCEI AVHRR LAI product was generated from the version 4 LTDR AVHRR reflectance data using artificial neural networks which were calibrated using the MODIS LAI product. The MODIS LAI product was aggregated to 0.05° to be consistent with the spatial resolution of the AVHRR reflectance data. The aggregated MODIS LAI and AVHRR reflectance data were further averaged monthly. The monthly averaged LAI and reflectance values over the BELMANIP2 sites during the 2001–2007 period were used to train artificial neural networks per land cover type. Then, the trained artificial neural networks were used to retrieve LAI for the corresponding land cover types from the LTDR AVHRR reflectance values in near real-time, thus allowing their use for monitoring purposes. The estimate of the NCEI AVHRR LAI is accompanied with quality assurance (QA) information. In this study, only the high quality LAI values were used to compare with other long time-series global LAI products according to the QA information.

2.1.3. GIMMS3g LAI product

The GIMMS3g LAI product was produced by Boston University. The temporal resolution is bi-monthly and the spatial resolution is 1/12° (about 8 km at the Equator). The GIMMS3g LAI product spans the period from 1981 to 2011. The GIMMS3g LAI product was derived from the GIMMS3g normalized difference vegetation index (NDVI) product using Feed-Forward Neural Networks (FFNNs) which were calibrated using the improved MODIS LAI product (Yuan et al., 2011). The GIMMS3g NDVI and improved MODIS LAI data were first composited into a monthly timescale, and the improved MODIS LAI data were further resampled to the same spatial resolution as the GIMMS3g NDVI data using bi-cubic resampling. Then, for each month, a FFNN was trained through back-propagation using the composited and resampled MODIS LAI and GIMMS3g NDVI data between 2000 and 2009 (Zhu et al., 2013).

2.1.4. GLOBMAP LAI product

The GLOBMAP LAI product from the latest version (version 2) was used in this study. The version 2 GLOBMAP LAI product provides a 0.08° spatial resolution on Geographic grid and spans the period from 1981 to 2015 (http://www.globalmapping.org/globalLAI/