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ScienceDirect
Remote Sensing of Environment 112 (2008) 75–93
Remote Sensing of Environment
www.elsevier.com/locate/rse

Spatially and temporally continuous LAI data sets based on an integrated filtering method: Examples from North America

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Received 27 April 2006; received in revised form 19 July 2006; accepted 24 July 2006

Abstract

Leaf Area Index (LAI) is an important biophysical variable for characterizing the land surface vegetation. Global LAI product has been routinely produced from the MODerate resolution Imaging Spectroradiometer (MODIS) aboard the Terra and Aqua satellite platforms. However, the MODIS standard LAI product is not continuous both spatially and temporally. To fill the gaps and improve the quality, we have developed a data filtering algorithm. This filter, called the temporal spatial filter (TSF), integrates both spatial and temporal characteristics for different plant functional types. The spatial gaps are first filled with the multi-year averages of the same day. If the values are missing over all years, the pixel is filled with a new estimate using the vegetation continuous field–ecosystem curve fitting method. The TSF integrates both the multi-seasonal average trend (background) and the seasonal observation. We implement this algorithm using the MODIS Collection 4 LAI product over North America. Comparison of the TSF results with the Savitzky–Golay filter indicates that the TSF performs much better in restoring the spatial and temporal distribution of seasonal LAI trends. The new LAI product has been validated by comparing with field measurements and the derived LAI maps from ETM+ data at a broadleaf forest site and an agricultural site. The validation results indicate that the new LAI product agrees better with both the field measurements and LAI values obtained from the ETM+ than does the MODIS LAI standard product, which usually shows higher LAI values.

Keywords: Leaf area index (LAI); Moderate Resolution Imaging Spectroradiometer (MODIS); Temporal and spatial filter; Remote sensing; Terra; Ecosystem curve fitting (ECF)

1. Introduction

Leaf area index (LAI) is being provided by the science team from observations acquired by the MODerate resolution Imaging Spectroradiometer (MODIS) instruments aboard NASA's Terra and Aqua satellites. However, the current LAI product is spatially and temporally discontinuous due to cloud cover, seasonal snow and instrument problems. This limits the application of LAI in ground surface process simulation, climatic modeling and global change research. Modelers would want continuous high quality data that can be used easily. While the QC (quality control) layers have some value, they need to be explored further in order to provide the highest quality data.

To enable these LAI products to be used with their various kinds of gaps, it is intuitively appealing to use either temporal or spatial filters. Several mathematical filters have been used to fill gaps in remotely sensed data, such as simple linear interpolation, best index slope extraction (Viovy et al., 1992), Fourier wave adjustment (Sellers et al., 1994), polynomial fitting (Karnieli et al., 2002), Asymmetric Gaussian filter (Jönsson & Eklundh, 2002), Savitzky–Golay filter (Chen et al., 2004; Savitzky & Golay, 1964), or piecewise logistic function fitting (Zhang et al., 2003). These methods have been mainly used to restore the NDVI (normalized difference vegetation index) profile (Cihlar, 1996; Sellers et al., 1994), but they can also be used for LAI with some adjustments.

Spatial filtering using pixel-level or regional ecosystem statistical data is provided by most commercial image processing software. Various spatial filters have long been adopted in digital data processing to remove noise or enhance surface features. Geostatistical methods, such as co-kriging and stochastic

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0034-4257/$ - see front matter
doi:10.1016/j.rse.2006.07.026

Table 1
The MODIS LAI quality control (QC) values and algorithms and the TSF algorithm treatments

QC values	SCF_QC (binary, decimal values)	MODIS LAI algorithms	TSF algorithms	
			Background	Observation
QC<32	000=0	Main (RT) method with the best possible results	Good data (not processed)	
32<=QC<64	001=1	Main (RT) method with saturation	Multi-year average or VCF–ECF method	Use original MODIS LAI as observation
64<=QC<96	010=2	Empirical method used (Main method failed due to geometry problems)		
96<=QC<128	011=3	Empirical method used (Main method failed due to problems other than geometry)		
QC>=128	100=4	Couldn't retrieve pixel		Temporal filtering

SCF_QC are the binary bits indicating LAI algorithms.

Table 2
Filled values in the standard MODIS LAI Collection 4 product

Filled values	Description
255	Not-computed or outside projection
254	Water (Ocean or inland)
253	Barren, very sparsely vegetated
252	Perennial snow or ice on pixel
251	Permanent wetlands, marshes
250	Urban, built-up areas
249	Unclassified

simulation, have been used for mapping vegetation variables (Dungan, 1998). Berterretche et al. (2005) reviewed several aspatial and spatial methods and compared reduced major axis, kriging with an external drift and sequential Gaussian conditional simulation to develop continuous LAI maps over a boreal forest study site. Nevertheless, techniques based purely on spatial methods are very limited because there are usually large regions that have poor spatial coverage, which cannot readily be filled. Furthermore, simple spatial filtering of an ecosystem may fail to represent the complexity of real landscapes. Ecosystem statistics only indicate the general characteristics of a small region, they cannot represent the spatial structure and continuous gradations that characterize real landscapes.

Moody et al. (2005) tried to combine both temporal and spatial methods and developed an ecosystem-dependent temporal interpolation technique to fill missing or snow-covered pixels in the MODIS albedo data product. The shapes of the pixel's and region's ecosystem phenological curves are determined first (Moody et al., 2005). The method imposes pixel and regional ecosystem phenological profile onto the target pixel's temporal data to maintain pixel-level spatial and spectral detail and integrity (Moody et al., 2005). This ecosystem curve fitting (ECF) method uses both spatial and temporal information to derive value-added data sets.

The ECF method cannot be simply applied to LAI products for several reasons. First, LAI is an 8-day composite product and its temporal curve is not as smooth as other daily products. There are realistic variations that look like outliers, for example those associated with crops in the growing season. Second, the LAI profile from the pixels with the same ecosystem classification may not represent the pixel itself. This is mainly due to the coarse land surface classification that is still problematic for mixed pixels. For example, 'cropland' could include corn, soybean or the mixture of the two. The ECF method assumes there are no mixed pixels for all the ecosystem classes. Most importantly, for the same ecosystem, their LAI could vary widely within a short distance due to different vegetation densities. For example, the tree cover of central Maryland, USA (15–45%) is about half of the typical temperate forest (50–90%) in the surrounding mountains (DeFries et al., 2000). Their albedos are very similar, but their LAI could differ by 2.0–3.0 (Fang & Liang, 2005). One of our studies in a semi-arid area also illustrates the problem of using the regional ecosystem average (Fang et al., 2005). The land cover maps label the study area as 'shrub'; however, the area is composed of about 20–30% trees, 20–30% grasses and 50% bare ground (Fang et al., 2005). Obviously, errors will be introduced to the ECF method if the vegetation fraction is not accounted in the curve fitting procedure.

The objective of this paper is to develop a filtering algorithm that aims to fill spatial and temporal gaps and improve bad quality values from contextual data (in space and time). In addition to many missing values, a significant amount of the MODIS LAI data is retrieved from the backup algorithm. We will first analyze

Table 3
Percentage of MODIS LAI product with different Quality Control flags for North America during 2000–2004

	PFTS	1	2	3	4	5	6	7	8	9	10	11
SCF_QC	0	47.6	37.8	43.2	43	59	57.8	54.3	53.8	48.7	22.3	41.1
	1	2	7.1	1.6	5.5	0.4	1	2.5	2.2	0.5	2.6	0.6
	2	5.1	4.7	5.3	4.6	5.4	5.1	5.7	4.1	3.4	1.4	4.3
	3	19.5	27.3	16.5	23.9	14.1	15.8	18	16.9	8.7	23.4	13.3
	4	25.8	23.1	33.3	22.9	21.1	20.2	19.5	23	38.7	50.3	40.7
Retrieval index		71.8	62.2	73.1	67	80.8	78.8	75.9	76.8	85	51.6	75.8

PFTs shows different plant functional types with 1–11 correspond to (a)–(k) in Fig. 1.
RI (Retrieval index)=(SCF_QC0+SCF_QC1)/(SCF_QC0+SCF_QC1+SCF_QC3).