Available online at www.sciencedirect.com
ScienceDirect
ISPRS Journal of Photogrammetry & Remote Sensing 63 (2008) 661–677
PHOTOGRAMMETRY & REMOTE SENSING
www.elsevier.com/locate/isprsjprs

Evaluation of MODIS surface reflectance products for wheat leaf area index (LAI) retrieval

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Received 7 August 2007; received in revised form 14 April 2008; accepted 14 April 2008
Available online 13 June 2008

Abstract

The accuracy of leaf area index (LAI) retrieval depends critically on the quality of the input reflectance. MODIS Collection 4 (C4) and Collection 5 (C5) land surface reflectance data are used for wheat LAI retrieval. Results are compared with in situ measurements. The uncertainty in the reflectance data of the two collections (C4 and C5) from both Terra and Aqua sensors is analyzed and its influence on LAI retrieval is discussed. The discrepancies of blue and near infrared reflectances between Terra and Aqua in the C5 data are less than the discrepancies between the sensors in the C4 data. For both Terra and Aqua, the C5 data have much lower blue reflectance than do the C4 data. This can be attributed to improvements in the atmospheric correction algorithm for the C5 data including cloud mask definition and aerosol retrieval. Using both empirical vegetation indices and inversion methods, the LAI is derived from the C4 and C5 surface reflectances. For daily C4 data, only Aqua Normalized difference water indices (NDWI) have significant correlations with the LAI (at a 99% confidence level); in contrast, for the daily C5 data, all the vegetation indices have significant correlations with the LAI. A three-layer neural network is used to invert a one-dimensional (1-D) radiative transfer model for LAI estimation. For the daily C4 data, the correlation between the modeled and measured LAIs is poor and the root mean square error (RMSE) is larger than 1.1; in comparison, the RMSE for the daily C5 data is 0.7. For both C4 and C5 collections, the LAI tends to be overestimated when the sensor is operated with a large view zenith angle in the backscattering direction. The error is either due to the mismatch between the measured reflectance and the modeled reflectance from the simple 1-D radiative transfer model in this direction or due to the assumption of a Lambertian surface in the MODIS atmospheric correction. Additionally, for both methods the results from the 8-day composite C4 data are much better than the results from daily C4 data because there is less cloud and aerosol contamination after compositing. In summary, the daily C4 reflectance has greater uncertainty than does the daily C5 reflectance. Daily C5 data are more preferable for LAI retrieval; if only C4 data are available, more reliable results can be achieved using the 8-day composite data if its temporal resolution is not a concern for dynamic growth monitoring.

Keywords: Leaf area index; MODIS; Model inversion; Vegetation index

1. Introduction

The leaf area index (LAI) is an important parameter in hydrological and ecological models to quantify

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0924-2716/$ - see front matter
doi:10.1016/j.isprsjprs.2008.04.004

canopy interception, evapotranspiration, photosynthesis and many other ecohydrological processes (Weiss et al., 2004). Direct measurement of the LAI is usually time-consuming and tedious. Indirect remote sensing techniques can provide a rapid way to map the LAI. Currently there are two common approaches to estimate the LAI from optical remote sensing imagery. The first is to develop empirical equations between the LAI and vegetation indices (VIs) and the second is inversion of radiative transfer (RT) models.

The normalized difference vegetation index (NDVI) is the most popular VI for LAI retrieval because of its simplicity and availability (Qi et al., 2000; Walthall et al., 2004; Houborg et al., 2007). However, the NDVI is not the best solution due to its sensitivity to external factors, e.g. the atmospheric condition, background variations and view geometry. Saturation of the NDVI at high LAI values is also a limitation to its application. As supplements, several indices have been proposed for LAI estimation purposes. The soil adjusted vegetation index (SAVI, (Huete, 1988)) and the modified soil adjusted vegetation index (MSAVI, (Qi et al., 1994)) were developed to consider the contribution of the soil background through aligning the VI isolines with the greenness isolines (usually expressed in terms of the LAI). The enhanced vegetation index (EVI, (Huete et al., 1999)) incorporates both background adjustment and atmospheric resistance concepts for correcting the interactive canopy background and atmospheric influences. Gao (1996) designed a normalized difference water index (NDWI) using 1240 nm and 860 nm wavelengths and showed that the NDWI was less perturbed by atmospheric effects than the NDVI. Chen et al. (2005) demonstrated that the NDWI using longer short-wave infrared (SWIR) wavelengths (1640 and 2130 nm) had later saturation and better correlation with vegetation water content for corn and soybeans than did NDVI.

The VI method is simple but the empirical relationship between the indices and the LAI varies with vegetation type. The inversion method, though more complex, is physically based and independent of vegetation type. Therefore, it is more general for applications. Three methods are widely applied to invert the RT models: conventional numeric optimization methods (e.g. Jacquemoud et al. (1995, 2000) and Houborg et al. (2007)), lookup table (LUT) methods (Combal et al., 2002), and neural network (NN) algorithms (e.g. Smith (1993), Gong et al. (1999), Danson and Rowland (2003), Fang and Liang (2003), Walthall et al. (2004), Bacour et al. (2006)). Direct inversion through traditional iterative processes to find values closely matching measurements is always time-consuming. In comparison, the two non-parametric methods (LUT and NN) can speed up inversion because the intensive computational part of the procedure is completed before the inversion itself. The NN method establishes a non-linear function between the simulated reflectance field and the biophysical variables of interest (Kimes et al., 1998). With support from a large database of experimental data, a neural network can be trained to estimate crop biophysical properties from spectral data more accurately than an empirical VI approach (Baret et al., 1995). The NN performance essentially relies on the training database. The research work of Combal et al. (2002) showed the necessity to improve the prior knowledge of uncertainties related to the reflectance measurements and the RT model structure for successful inversion.

Most previous efforts focused on vegetation parameter retrieval either using satellites with high spatial resolution, such as Landsat TM/ETM+, and airborne and ground sensors (Jacquemoud et al., 2000; Eklundh et al., 2001; Fang and Liang, 2003; Colombo et al., 2003; Meroni et al., 2004; Gascon et al., 2007), or using simulated reflectance fields (Gong et al., 1999; Danson and Rowland, 2003). However, due to cloud contamination, high spatial resolution images often suffer poor temporal coverage, and sometimes only one or two images can be obtained during the growing season. Therefore, it is not favorable for analyses of the small-scale temporal and spatial variability of crop conditions. The MODerate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites provides earth observations twice a day on a near-daily basis (every other day at the equator) at a moderate spatial resolution from 250 to 500 m, which makes it appealing for crop biophysical parameter retrievals (Houborg et al., 2007). However, most work using MODIS data for LAI retrieval to date has been limited to 8-day composite data (Doraiswamy et al., 2004; Fang and Liang, 2005; Houborg et al., 2007) and little work has been done on analyzing the effects of the data uncertainty of MODIS daily reflectance on the LAI estimation.

Recently, MODIS Collection 5 (C5) land reflectance products have been released and algorithms for atmospheric correction including cloud mask definition and aerosol retrieval have been refined in comparison to algorithms for Collection 4 (C4) products. It is desirable to know how much improvement can be achieved in LAI retrieval using the new dataset. Therefore, the objectives of this study are (1) to compare the two collections of MODIS reflectance products for evaluating the