LEAF AREA INDEX RETRIEVAL USING IRS LISS-III SENSOR DATA AND VALIDATION OF MODIS LAI PRODUCT OVER INDIA

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ABSTRACT:
This paper reports results of an experiment LRVE (Leaf Area Index Retrieval and Validation Experiment) that was conducted over agricultural areas of Central India during winter season of 2001-02, aimed at relating field measurements of LAI to space borne IRS LISS-III data, preparation of site-level LAI maps and validation of MODIS-based 1 km LAI global fields,. Measurements of field-level LAI, aerosol optical thickness and water vapor were carried out on the day of LISS-III overpass. Empirical models based on site-specific LAI-vegetation index relation were developed and used to generate 23-meter resolution LAI maps for two sites (Indore and Bhopal) covering 30 km X 30 km. These LAI images were aggregated to 1km spatial resolution and used for validation of MODIS LAI product (MOD15A1). The results indicated significant positive correlation between LAI derived from LISS-III data and MODIS data, with an overestimation in the MODIS product, with RMSE of 0.92 to 1.26 for Bhopal site and 0.20 to 0.33 for Indore site. Analysis of MODIS land cover product that forms an input in MODIS LAI retrieval algorithm, indicated error in assigning land cover class over the study sites and that could be a source of error in MODIS LAI product.

1. INTRODUCTION

The Leaf area index (LAI) is one of the most important parameters characterizing a canopy. LAI is a dimensionless index used to quantify the single sided vegetation leaf area per unit of ground area in broadleaf canopies (or projected needle leaf area in coniferous canopies). It is one of the surface parameters that plays key role in climate, weather and ecological studies. LAI is a biophysical variable influencing vegetation photosynthesis, transpiration and the energy balance of canopies (Bonan, 1993). LAI and fraction of absorbed photosynthetically active radiation (0.4 – 0.7 mm) (fAPAR) are important surface attribute controlling water, carbon and energy exchanges between vegetation and the atmosphere (Running *et al*., 1996). LAI is not only an important driver of most ecosystem productivity models operating at landscape to global scales (Turner *et al*., 1999), but also an interaction component of general circulation models (Buermann *et al*., 2001).

Amongst the many surface biogeochemical parameters, which can be derived from satellite spectral measurements, LAI is a vegetation structural parameter of fundamental importance for quantitative analysis of many physical and biological processes related to vegetation dynamics, global carbon cycle and climate. Estimation of LAI at frequent intervals can facilitate estimates of mass and energy exchange over a wide range of spatial scales and with considerable temporal resolution. Ground measurements of LAI however are cumbersome, time consuming and impossible to obtain at global scale, while satellite remote sensing is the most effective means of estimating LAI global fields on a regular basis.

As part of the US Earth Observing System (EOS), the Terra (launched in December 1999) and Aqua (launched in May 2002) satellites, carry the Moderate resolution Imaging Spectroradiometer (MODIS) along with a host of other advanced sensors. Algorithms have been developed to generate a number of land products from MODIS, including LAI/FPAR and that have been made available through from EROS Data Center Data Archive Center (EDC-DAAC) for evaluation/validation and utilization. The MOD15 LAI and FPAR are 1km products provided on a daily and 8-day basis. The validation of LAI global fields, i.e., assessment of uncertainty of remote sensing derived products by analytical comparison to reference data which are presumed to represent the target values (Justice *et al*., 2000), is necessary and has been carried out for many sites over USA, Africa (Privette *et al*., 2002) and elsewhere, but no results are available over India. A LAI Retrieval and Validation Experiment (LRVE) aiming at development of remote sensing based site-specific vegetation index-LAI relations and validation of MODIS LAI product was conducted at Indore and Bhopal during the wheat-growing season of 2001-02. The experiment had three components, (1) the field measurements of LAI and atmospheric properties (aerosol optical depth and water vapor); (2) generation of fine resolution (23m) LAI map from IRS LISS-III and field data; and (3) the generation of 1-km LAI maps and their comparison with MODIS LAI product.

2. MATERIALS AND METHODS

2.1 Ground sites description

Two sites in the state of Madhya Pradesh of India, Indore and Bhopal were selected for LAI measurements. These sites represent semi arid and semi humid zone respectively. Both the sites have black cotton soil. The sites had wheat as a major crop with small proportion of other crops like gram and pea. Indore has rainfed agriculture and Bhopal has irrigated agricultural practice. The study area and the remote sensing data used in the LRVE are shown in table 1.

Table 1: LAI sites and details of satellite data acquisitions

Description	Site: Indore	Site: Bhopal
Site location Long., lat.	75^0 57' E, 22^0 53' N	77^0 28' E, 23^0 10' N
Date of IRS-1D LISS-III* acquisitions	02 Dec 01 27 Dec 01 21 Jan 02 #	24 Dec 01 18 Jan 02 # 12 Feb 02
IRS-1D Path/Row	96/56	97/55
Date of MODIS LAI 8-day product	3Dec.-10Dec. 2001 27Dec.2001-3Jan.02 --	19Dec.-26Dec. 2001 -- 10Feb.-17Feb. 2002
MODIS Tile Number	24H 6V	25H 6V

* LISS-III has green, red, nir bands (spatial resolution: 23 m), swir band (spatial resolution: 70 m)

Overcast conditions, hence not used in analysis

2.2 Satellite data used

2.3 IRS LISS-III

The data of Linear Imaging Self Scanning sensor-III (LISS-III) onboard Indian Remote Sensing satellite IRS-1D was used in the study. The LISS-III sensor has multispectral bands in green, red, near infrared (NIR) with 23 meter and short wave infrared (SWIR) with 70 meter spatial resolution.

2.4 The MODIS LAI product/algorithm

The MODIS LAI/FPAR product is produced at 1 km spatial resolution daily (MOD15A1) and composited over an 8-day period, where the selected value in a compositing period is that with the highest corresponding fraction of absorbed photosynthetically active radiation (FPAR). The 8-day product (MOD15A2) is distributed from the EROS Data Center. The products are projected on the Integerized Sinusoidal (IS) 100 grid, where the globe is tiled into 36 tiles along the east-west axis, and 18 tiles along the north-south axis, each approximately 1200X1200 km.

A brief summary of LAI algorithm is provided by Myneni *et al*., (2002). The algorithm is based on rigorous three-dimensional radiative transfer (RT) theory (Myneni *et al*., 1990). A look-up table (LUT) method is used to achieve inversion of the three-dimensional RT problem. The 250 and/or 500 m resolution bands are aggregated into normalized 1 km resolution grid cells prior to ingest (Wolfe *et al*., 1998).

The algorithm also employs a 1 km land cover map stratified by six major world biomes (grasses/cereal crops, shrubs, broadleaf crops, savannas, broadleaf forests and needleleaf forests). Look-up tables are then generated for each biome by running the model for various combinations of LAI and fractional cover. During algorithm execution, the algorithm compares the modeled and observed reflectances for a suite of canopy structures and soil patterns that represent the range of expected natural conditions. All canopy/soil patterns for which modeled and the observed reflectances are considered acceptable solutions. A scale-independent test of energy conservation is also applied. The mean LAI for this solution set is reported as the MODIS LAI product values. When this method fails to provide a solution, a backup algorithm based on relations between the vegetation difference vegetation index (NDVI) and LAI (Knyazikhin *et al*., 1998) is employed along with a biome classification map.

2.5 Experimental measurements of LAI and atmospheric parameters

The objective was to make LAI measurements and to generate site-specific LAI map. Therefore a suitable site of 30 km X 30 km representing the region was focused at two locations. The sites had adequate variability in terms of sowing date and variability in LAI. Optical methods were used in this study to acquire a large number of data points. LAI-2000 Plant Canopy Analyzer (LI-COR Inc.) was used to measure LAI in the fields. It is based on "fisheye" measurement of diffuse radiation interception by measuring gap fraction. The LAI-2000 measures attenuation of diffuse sky radiation at five zenith angles simultaneously (approximately 0-13^0, 16-28^0, 32-43^0, 47-58^0, 61-74^0). The measured gap fraction data are inverted to obtain the effective LAI under the assumption of a random spatial distribution of leaves. All the measurements were taken by holding the sensors opposite to the direction of the sun. A 90^0 mask was used to prevent interference caused by the operator's presence. A 270^0 mask was used in some fields of Bhopal because of heterogeneous distribution of trees around the fields. The LAI measurements were collected at six to eight locations within a field (with each observation being based on six point measurements) in order to obtain representative field LAI values. A total of 75 fields were sampled at various growth stages (monthly once, for three months at two sites) of the crops. The LAI measurements were carried out mainly for wheat crop with few observations on gram and pea. The locations of fields were marked on FCC paper prints and also determined with Global Positioning System (GPS).

The atmospheric measurements of aerosol optical thickness (AOT) and water vapor content were carried out concurrently with the LAI measurements on the date of IRS-1D satellite acquisitions using handheld Microtops-II Sunphotometer with five optical collimators working at 500, 675, 870, 936 and 1020 nm and a full field of view of 2.5^0.

2.6 LAI map validation procedure

The ground plots, in which LAI was measured, were generally 25-75m in size. Because of the surface heterogeneity (cover type and density changes), it was necessary to use fine-resolution images, in which ground plots can be located accurately to validate low-resolution products. The procedures for LAI map validation were:

1) Selection of representative areas in the Central India regions and identification of IRS LISS-III scenes covering these areas;
2) Collection of LAI data in multiple (30-40) plots within each LISS-III scene using the same types of instruments and following the same measurement protocols;
3) Identification of ground plots in the scenes and extraction of the remote sensing data for each of the plots;
4) Development of non-linear LAI-NDVI model for different sites using satellite and field data.
5) Generation of LAI maps for each site using the model developed.

6) Degradation of the LISS-III LAI maps into low resolution to compare and evaluate MODIS LAI product.

2.7 Remote sensing data analysis and image processing

LAI may be estimated at a variety of spatial scales and with different space-borne sensors (Chen and Cihlar, 1996) using techniques ranging from regression models to canopy reflectance model inversions with varying successes, which include (1) statistical models that relate LAI to band radiance (Badhwar *et al*., 1986) or develop LAI-vegetation index relation (Chen and Cihlar, 1996 and Myneni *et al*., 1997), (2) biophysical models like Price (1993), and (3) inversion of canopy reflectance using numerical model or LUT based model (Gao and Lesht, 1997, Qiu *et al*., 1998, and Knyazikhin *et al*., 1998). The empirical approach is common in large area remote sensing LAI estimation and it is used in the present study.

The complete procedure is shown in figure 1. For each site, an area of approximately 30 km X 30 km was extracted from IRS-1D LISS-III. Digital numbers (DN) were converted to top-of-atmosphere (TOA) reflectance using the sensor gain, offset, sun-angle and exo-atmospheric band pass coefficients (Pandya *et al*., 2002). Surface reflectance was calculated from TOA reflectance using the 6S-code (Vermote et. al., 1997) using measured aerosol optical thickness (AOT) and water vapor (wv) at site as input. Out of six IRS-1D LISS-III acquisitions (table 1), two were cloudy and not used in analysis. The reflectance images were registered to corresponding geo-rectified images using nearest neighbor resampling with less than 0.5 pixel root mean square error. The fields with LAI measurements were identified and demarcated carefully on the corresponding LISS-III and Panchromatic (PAN) merged (5.8 m spatial resolution) data. The mean NDVI was computed for each field. Site-specific non-linear NDVI-LAI relations were developed for each site and acquisition. The exponential and polynomial fits were found to have higher R^2 (0.58-0.73) than the linear fits (0.3-0.52). The exponential form of models was used to generate the fine resolution LAI maps from LISS-III data for each site and date (e.g. figure 2). These LAI images were aggregated (figures 3(a) and 4(a)) to 1 km spatial resolution using averaging for comparison with MODIS LAI product.

The MODIS LAI product of 1 km spatial resolution and composited over an 8-day period corresponding to 10^0 X 10^0 tiles in HDF EOS format were acquired for study area from EROS Data Center (table 1) and these were reprojected from original Integerized Sinusoidal projection to UTM projection. The LAI images (figures 3(b) and 4(b)) were generated by applying scaling factor after masking out water and urban pixels. Quality flags supplied with MODIS LAI products were studied and inter-comparison between LISS-III LAI and MODIS LAI was restricted to pixels pertaining to the class of overall best quality (cloud free pixels and LAI retrieval through RT model).

3. RESULTS AND DISCUSSION

3.1 Variability in LAI and atmospheric measurements across sites

Information on sites, date of LAI measurements, crops covered, range of LAI, AOT and water vapor measured are summarized in the table 2. The LAI for the crops considered, span a wide range corresponding to crop emergence to peak vegetative stage. The range of LAIs across all sites/season was from 0.14 to 5.6. The range of AOT measurements collected at the time of satellite pass across the sites was 0.16 to 0.32 at 500 nm and the range of water vapor was 0.71 to 1.28 cm.

Table 2: Range of LAI and atmospheric parameters across sites/dates

Site No*	Date of Ground Observation	Crop**	LAI Range	AOT at 500 nm	Water vapor (cm)
1	02 Dec 01	w,g	0.17-3.30	0.16	0.71
	27 Dec 01	w,g	0.69-4.63	0.26	1.15
	21 Jan 02 #	w,g	0.64-3.26	--	--
2	24 Dec 01	w,g,p	0.14-3.80	0.2	0.51
	18 Jan 02 #	w,g,p	1.05-5.6	--	--
	12 Feb 02	w,g p	1.25-4.48	0.32	1.28

* Site No: 1: Indore, 2: Bhopal, ** w: wheat, g: gram, p: pea
# Overcast conditions

3.2 Site specific LAI-NDVI empirical models and validation of MODIS LAI

After atmospheric correction, the contrast of red and NIR increased and consequently the estimated NDVI was higher than those computed with DN and radiance of red and NIR (figure 2). The exponential form of models was used to generate the fine resolution LAI maps from atmospherically corrected LISS-III data. The model coefficients for different sites/dates are summarized in table 3.

Table 3. Regression models to relate LAI to NDVI derived from LISS-3 data, Equation: y=a + b ln(x), y=NDVI, x=LAI

Site	Date	a	b	R^2
Bhopal	24 Dec.2001	0.5847	0.1225	0.73
	12 Feb.2002	0.5197	0.1634	0.58
Indore	02 Dec.2001	0.5156	0.1341	0.65
	27 Dec.2001	0.4776	0.1425	0.60

The comparison between LISS-III derived LAI and MODIS LAI was carried out by performing regression between LAI estimated from MODIS (dependent) and LISS-III (independent) and the results are summarized in table 4 and illustrated in figure 5. The comparison indicated significant positive correlation between LISS-III derived LAI and MODIS LAI (r=0.78 for Bhopal and r=0.72 for Indore). A slope of 1 and 0 intercept indicate full match, while deviations show over/under estimation. The analyses indicated an overestimation in MODIS LAI compared to LISS-III LAI for both sites. The scale of overestimation is quite high for Bhopal (slope: 1.98 and 2.49) than Indore (slope: 0.74 and 1.16). Overestimation by LAI was higher, for higher LAI estimates by LISS-III, especially in Bhopal (figure 5 (a), (b)). The overall root mean square error of MODIS LAI is higher for Bhopal (0.92 and 1.26) compared to Indore (0.20 and 0.33), however Bhopal had higher range of LAI (0.1 to 3.28 in LISS-III LAI, 0.3 to 6.9 in MODIS LAI). During the analysis, many pixels of MODIS LAI product were observed to have LAI (5-6.9), which seems to be unrealistically high and contrary to the ground observations. Similar trend was observed for other dates and site. Since comparison is restricted to only best RT-model derived pixels, the errors could arise due to a number of factors such as wrong biome type, vegetation dependent parameters and effect of soil background or aggregation procedure. Analysis of MODIS land cover product that goes as an input in MODIS LAI retrieval algorithm, indicated error in assigning land cover class over the study sites (broad leaf crop biome class has been considered instead of grasses-cereal crop biome class) and that could be a source of error in MODIS LAI product. Myneni *et al*., (2002) have shown when misclassification of land cover happens between such classes LAI retrieval indicated overestimation of approximately 20 percentages. A preliminary analysis using all pixels including partially cloudy pixels and LAI retrieval through backup algorithm indicated a much higher scatter between MODIS LAI and LISS-III estimated LAI. However, significant correlation gives an indication of good performance of MODIS LAI product. However, additional studies are needed before using the product in operational use.

Table 4: Regression models to relate MODIS LAI and LAI derived from LISS-3 data
Equation: y = a + bx, y=MODIS LAI, x=LISS-3 LAI

Site	Date	a*	b*	R^2	RMSE
Bhopal	24 Dec.2001	0.433 (0.054)	2.4980 (0.073)	0.61	0.92
	12 Feb.2002	0.419 (0.089)	1.9874 (0.058)	0.61	1.26
Indore	02 Dec.2001	0.571 (0.013)	1.1643 (0.04)	0.52	0.20
	27 Dec.2001	0.681 (0.021)	0.7477 (0.026)	0.51	0.33

* Numbers in bracket indicate RMSE

4. CONCLUSIONS

A study to compare/validate the MODIS LAI product with the LAI images generated from IRS LISS-III data using regression model between field-measured LAI and NDVI is presented. A significant positive correlation indicates good performance of the MODIS LAI product. However, for a few scattered pixels of MODIS product high LAI was observed. Similar trend was observed for other sites. The reason of difference in LAIs could arise due to many factors such as wrong biome type, effect of soil background, or due to aggregation. Thus different aggregation procedures (such as fractal based aggregation method, Milne and Cohen, 1999) have to be tested to confirm this. Since the observations were made majorly over wheat crop, with less LAI, observation on other crops and natural vegetation are essential for broad scale validation of LAI product. Detailed modeling and observation experiments using reflectance data at two different spatial resolutions may be necessary to identify the cause of this overestimation. It may be pointed out that LAI is spatially very heterogeneous quantity, and is associated with high uncertainty in field observations and other procedures. However, additional studies, covering more sites and vegetation types are underway before using the product in operational use.

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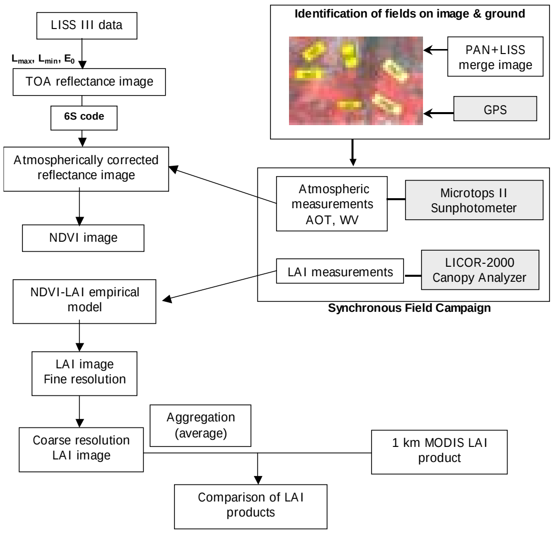

Figure 1. Procedure describing retrieval of LAI from IRS LISS-III data and its comparison with MODIS LAI product

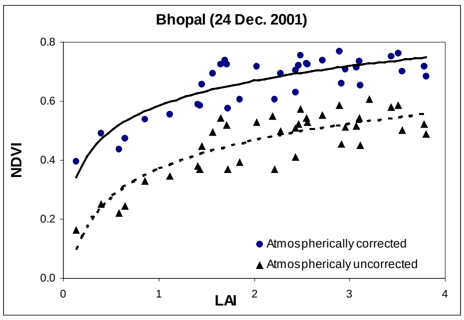

Figure 2. Relationship of ground measured LAI on wheat fields with IRS LISS-III derived NDVI

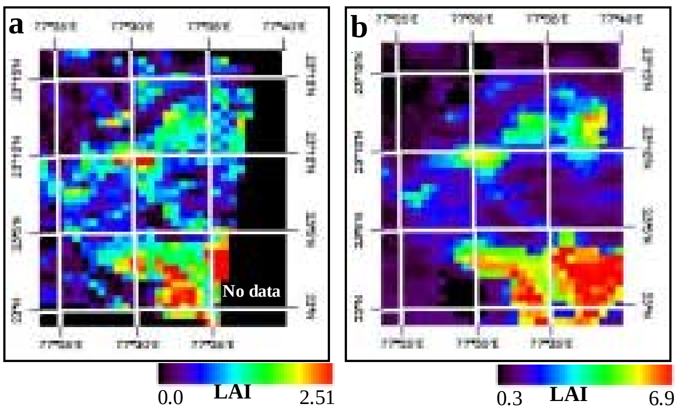

Figure3. (a) LAI map retrieved from LISS-III Bhopal site, 24 December 2001. (b) MODIS LAI product, 8-day composite (19-26 December 2001)

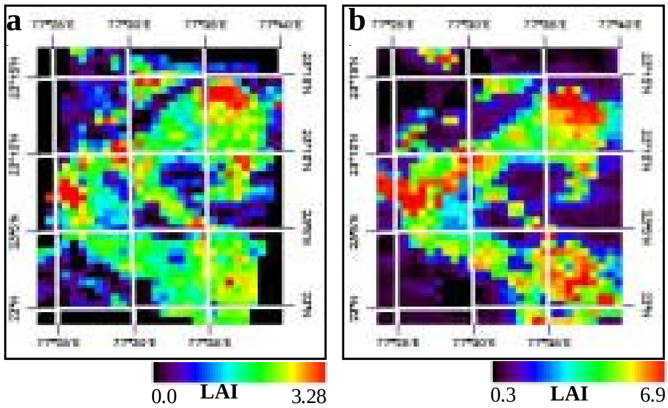

Figure 4. (a) LAI map retrieved from LISS-III Bhopal site, 12 February 2002. (b) MODIS LAI product, 8-day composite (10-17 February 2002)

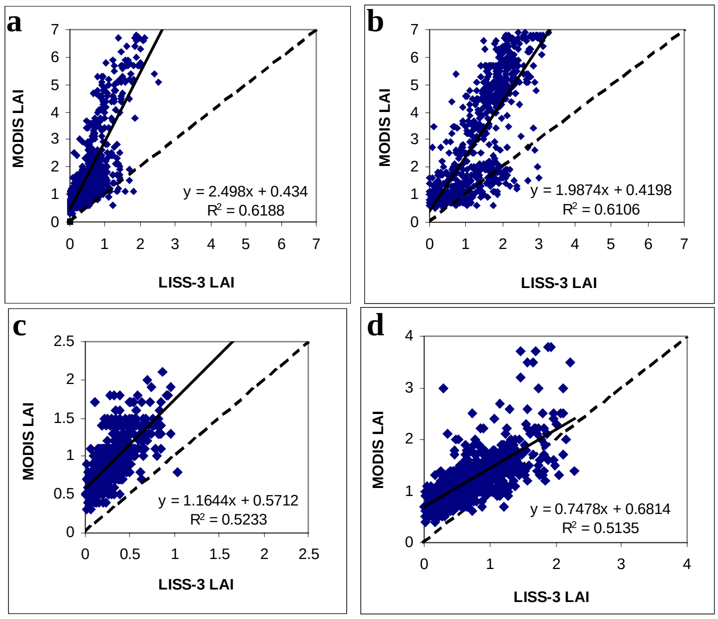

Figure 5. Comparison of LISS-III LAI and MODIS LAI over Bhopal site. (a) 24 Dec. 2001 (b) 12 Feb.2002 and over Indore site. (c) 2 Dec. 2001 (d) 27 Dec. 2001