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Leaf Area Index Retrieval Using IRS-1D LISS-III Data – A Case Study in Gujarat

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ABSTRACT

Leaf area index is one of the important parameters in crop simulation models and is also required for variety of applications. Generation of LAI map for spatial applications of crop simulation models and crop monitoring is the need of the hour. An experimental programme on LAI retrieval using IRS-1D LISS-III data and its validation with real time ground measurements was planned and initiated during December 2001 over six different sites in India. The data pertaining to two sites (Anand : 72° 37'E, 22° 48'N, Chharodi : 72° 16'E, 23° 02'N) in Gujarat having wheat and wheat/tobacco as dominant crops respectively are analyzed. The results showed that the exponential relationship exists between atmospherically corrected NDVI and measured LAI in Chharodi on 8 January 2002 over wide LAI range of 0.1 - 2.5 with R^2=0.61. But poor correlation was found in Anand on 30 January 2002 for narrow LAI range when majority of measured LAI data fall between 2.2-3.2. However, the exponential relation was found in case of pooled datasets of Anand and Chharodi with 63% correlation for the single year (2002) and 59% correlation for the pooled data of 2002 and 2003. The exponential model obtained from pooled datasets was used afterwards to develop LAI map for the study region.

Leaf area index (LAI) is defined as the total one sided green leaf area per unit soil area and is regarded as one of the important parameters characterizing a canopy. The accurate estimation of LAI is very much essential for estimation of net primary production (NPP) (Nemry *et al.*, 1996), in steering of crop simulation models (Moulin *et al.*, 1998) and a number of modeling studies related to agricultural meteorology (Wiegand and Richadson, 1984; Kergot, 1999). though ground measurement of LAI is relatively precise, but it involves more time and manpower for its assessment over large agricultural region based on few point observations. Therefore, the satellite based remote sensing technique having synoptic coverage is the best option for deriving spatial and temporal variability of LAI over large area. A number of techniques including simple regression approach to the inversion of canopy reflectance (CR) models have been attempted with satellite data. Broadly, there are two main approaches for retrieval of LAI (1) empirical model between LAI and individual band radiances or a vegetation index (Clevers and Verhoefs, 1993; Wiegand and Richadson, 1990) (2) physical models (Myneni *et al.*, 1997, Goel and Thompson, 1984). Even though the CR based approaches are more physical, rigorous in their treatment and best suitable for agricultrual croplands, they are not popular because of the complexities involved in inversion. Therefore, the simple regression approach drew attention from the scientific community for its applicability over local region. Presently, retrieval and validation of LAI from remote sensing data is an active field of research (Nemani *et al.*, 1993, Cihlar *et al.*, 2002). Global (Myneni, 1997; Bicheron and Leroy, 1999) and regional LAI maps (Cihlar *et al.*, 1997; Liu *et al.*, 1999; Chen *et al.*, 2002) have also been produced. Knyazikhin *et al.* (1999) has proposed a look-up-table based LAI retrieval algorithm for generating an operational 8-day composite LAI product at a spatial resolution of 1km. However, before its operational application there is a need to validate this product.

A LAI retrieval and validation experiment (LRVE) 2001-2003 was conducted at six sites in four states of North-West India during *rabi* 2001-2002 and 2002-2003, to develop a local spectral index-LAI model, using near infrared (NIR) and red band data of IRS-1D LISS-III sensor. This paper reports the results of LRVE over two sites in Gujarat.

Study area and datasets

The study sites included Anand (lat/long: 72° 37'E, 22° 48'N and path/row: 93/56) and Chharodi (lat/long: 72° 16'E, 23° 02'N and path/row: 92/56), which fall under the semi-arid zone having black cotton soil. While Anand is having predominantly mixed cropping of wheat, tobacco interspersed with tree boundaries, mostly mono-cropping with wheat is prevalent in Chharodi site during *rabi*/season. The data of Linear Imaging Self Scanning sensor-III (LISS-III) onboard IRS-1D was used for the spectral analysis. LISS-III sensor has multispectral bands in green( ), red( ), near infrared (NIR) with 23 m spatial resolution and short wave infrared (SWIR) band with 70 m spatial resolution with 25-day temporal resoltuion.

Methods

Measurement of LAI and atmospheric parameters

The LAI measurements were carried out using LICOR-2000 Plant Canopy Analyzer, based on "fisheye" measurement of diffuse radiation passed through canopy gap fraction. The LAI measurements were carried out at six random locations within each field where each observation is the average of six point measurements. A total of 72 fields were sampled at various growth stages with different crops for two years. The location of the fields were marked on FCC and also determined with Global Positioning System (GPS). The atmospheric measurements of aerosol optical thickness (AOT), water vapour content (w) and sun zenith angle (θ_s) were done concurrently with the LAI measurements, using a handheld Microtops-II Sunphotometer with five optical collimators working at 500, 675, 870, 936, 1020 nm and a full field of view of 2.5°. The real time measurements on LAI and atmospheric parameters would not be done due to lack of instrument availability. But the measurements corresponding to IRS- 1D LISS-III pass time were taken 2-5 days before IRS- 1D passes.

Data analysis and image processing

For both the sites, subscenecs covering 1200x1200 pixels surrounding the study area were extracted from the IRS- 1D LISS-III data. Digital numbers (DN) of the images were converted ito radiance using the sensor gain and offset provided in the image header and then radiance was converted into the top-of-atmosphere (TOA) reflectance using the band pass co-efficients given by Pandya *et al.* (2002). The top-of-atmosphere reflectance being contaminated by the noise signal of the intervening atmosphere, the surface reflectance was calculated from TOA reflectance using the 6S atmospheric correction code (Vermote *et al.*, 1997), using the measured atmospheric parameters (AOT, w) and solar zenith angle (θ_s) at the observation sites as inputs. The reflectance images were geo-registered using nearest neighbourhood resampling. The fields within the region of interest (ROI) were identified on the extracted LISS-III subscences. The average red and NIR reflectance were extracted for the different fields and the NDVI=(NIR-red)/(NIR+red) was computed for each field. Regression studies were carried out between atmospherically corrected NDVI and LAI for the region of interest (ROIs). This model was then used for generating LAI map for the study area. Fig. 1 gives detailed flow path of the analysis. The image analysis was done using ENVI 3.4 image processing software and IDL 5.4 language.

Results and Discussion

Atmospheric parameters and variability of LAI

The data on *in situ* measurement of LAI and the input parameters required for atmospheric correction such as: total water vapour content (w) and aerosol optical thickness (AOT) are given in Table 1. The range of LAI was found to be between 0.1-2.44 for Chharodi on January 3, 2002. The dominant crop type in the observation site was wheat at CRI/tillering stage. In Anand, it ranges from 2.18 to 4.28 on January 25, 2002 for wheat corresponding to flag leaf to soft dough stage and tobacco and from 0.54 to 3.81 for wheat corresponding to tillering initiation stage on January 17, 2003. The total water vapour contents were measured to be 0.92, 1.70 and 0.47 g/m^2 for

Table 1. Field measured atmospheric correction parameters and LAI ranges in Anand and Chharodi

Sites	Date of Obs.	Crop	Total water vapour (g/m^2)	AOT at 550 nm	LAI range	SD LAI
Chharodi	03.01.2002	Wheat	0.92	1.460	0.1-2.44	0.110
Anand	25.01.2002	Wheat & Tobacco	1.70	0.413	2.18-4.28	0.208
Anand	17.01.2003	Wheat	0.47	0.162	0.54-3.81	0.180

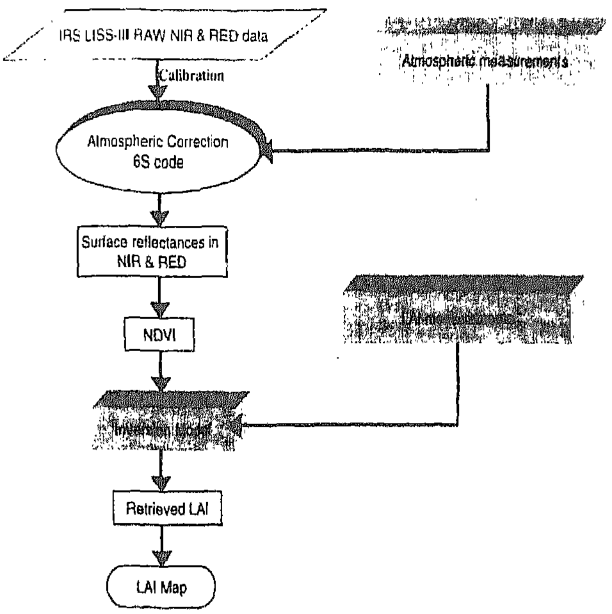

Fig. 1. Flow chart for the retrieval of LAI

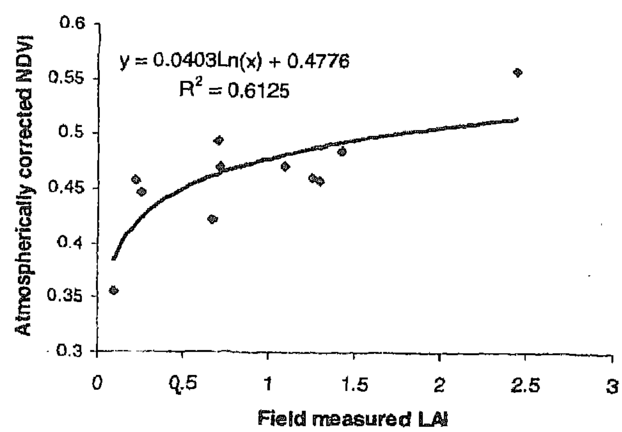

Fig. 2. LAI-NDVI relationship at Chharodi on 8th Jan., 2002 (CRI to maximum tillering)

Chharodi and Anand respectively. The measured aerosol optical thickness (AOT) at 550 nm was 1.46, 0.413 and 0.1625 respectively. The LISS-III data were atmospherically corrected for Chharodi and Anand site using the atmospheric parameters (AOT, w) and sun zenith angle (θ_s) measured on observation dates given in table 1 as input to 6S atmospheric correction code. The atmospherically corrected mean NDVI of marked ROIs were obtained where ground observation was carried out.

LAI-NDVI model

As the date of observations were 2-5 days before dates of satellite passes, the field measured LAI on observation dates were utilized to develop NDVI-LAI relationship. The regression studies showed an exponential relationship (Fig. 2) between corrected NDVI and LAI with R^2=0.613 at Chharodi on January 8, 2002 with 11 data points. But, poor relation occurred in case of Anand on January 30, 2002 with 24 data points. The data points of both the sites at different dates were then pooled together and the relationship with pooled datasets corresponding to different observational dates were found to be exponential (Fig. 3) with R^2=0.624 for 35 data points. Majority of data points for LAI at Anand were within a narrow range of 2.2-3.2 for a narrow NDVI range 0.63-0.73, which might have led to poor relation between these two. Since, the range of observed LAI was very wide in pooled dataset falling between 0.1-4.3 corresponding to a large NDVI range of 0.3-0.75, higher correlation existed in the pooled dataset. The pooled datasets of both the years *i.e.* 2001-2002 and 2002-2003 was also found to be exponential (Fig. 4) with R^2=0.596. Higher correlation exists in case of pooled datasets for the same year (R^2=0.624) than across the year

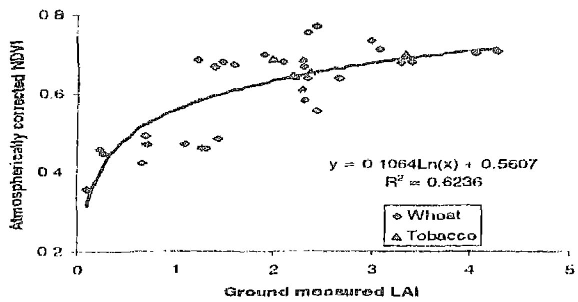

Fig. 3. LAI-NDVI relation for the pooled data over Anand and Chharodi site of Gujarat for *rabi* 2001-2002

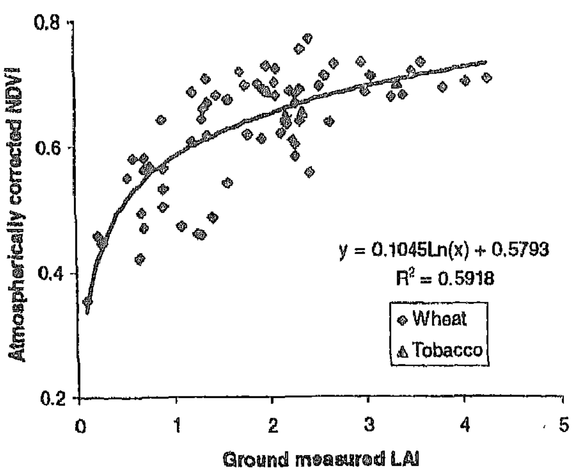

Fig. 4. LAI-NDVI relation for the pooled data over Anand and Chharodi site of Gujarat for the *rabi* season of 2001-2002 and 2002-2003

(R^2=0.596). The exponential LAI-NDVI model obtained from pooled dataset was then applied to generate LAI map of Anand and Chharodi. Fig. 5 and 6 respectively showed the correlation between the retrieved LAI and field measured LAI using a single year model (for the year 2001-2002) and common model (for both the year 2001-2002 and 2002-2003). the results showed that LAI can be retrieved with lower mean absolute bias (MAB=0.48) with R^2=0.519 and RMSE=0.361 using the single year model than the common model (MAB=0.50) with R^2=0.519 and RMSE=0.360.

Conclusion

The exponential model from the spectral index-LAI relationship could be found with reasonable

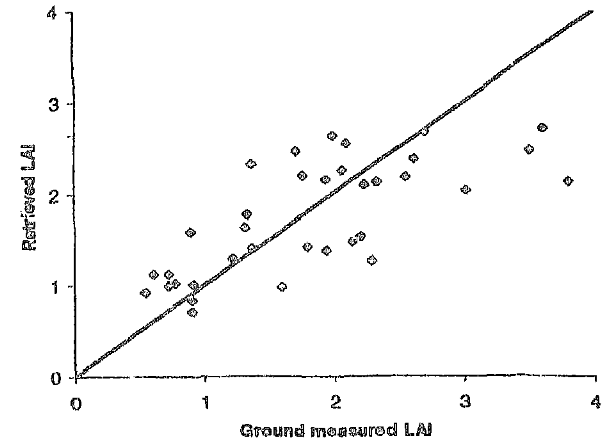

Fig. 5. Retrieved LAI vs ground measured LAI using single year model for 15th January 2003 at Anand site of Gujarat

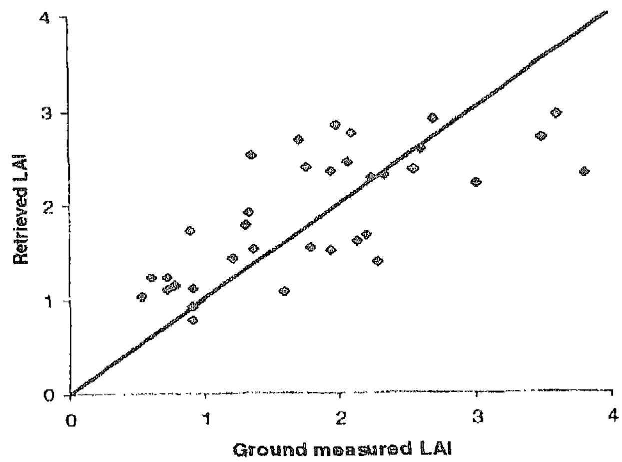

Fig. 3. Retrieved LAI vs ground measured LAI using single year model for 15th January 2003 at Anand site of Gujarat

correlation in Gujarat. From the analysis it was observed that the development of the generalized spectral based LAI model need large number of datasets covering wide LAI range between different crop growth stages. The future study in LRVE programme emphasizes on (1) retrieval of LAI based on physical model with high-resolution hyper spectral satellite data and its validation (2) aggregation of high resolution LAI map into coarse resolution.

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