RELATION BETWEEN LAND COVER PARAMETERS AND BRDF MODEL COEFFICIENTS-A CASE STUDY USING MODIS BRDF PRODUCT OVER PARTS OF WESTERN INDIA

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ABSTRACT:

In this paper, the BRDF data product from Moderate Resolution Imaging Spectrometer (MODIS) on EOS is used along with IRS - 1D WiFS and IRS 1D LISS-III sensors to explore relations between land cover classes, LAI and the BRDF model coefficients. The IRS -1D WiFS data was aggregated to the spatial resolution of MODIS (~ 1km) and the three BRDF model parameters corresponding to isotropic, volume and geometric components of surface reflectance for sand, water and crop classes are extracted and analyzed in this study. Using field measurements of LAI carried out at the Central State Farm, Suratgarh, Rajasthan along with LISS-III image of the same area, an LAI image of the farm was generated and the LAI values were correlated with the three MODIS BRDF model parameters. Small but significant negative correlations (~ 0.5) were found between LAI and angle independent isotropic term at both red and near infrared wavelengths and higher significant correlations were observed among the BRDF model coefficients.

1. INTRODUCTION

The Bi-directional Reflectance Distribution Function (BRDF) specifies the behavior of surface scattering as a function of illumination and view angles at a particular wavelength. The variation of surface reflectance with solar zenith and azimuth angles as well as view zenith and azimuth angles has important and non-trivial implications in the interpretation of remotely sensed data. Firstly, since radiance measurements of the same surface will vary with viewing geometry as well as solar (illumination) geometry, incorrect scene inference may occur when the same surface is viewed under different sun-target-sensor geometry. Secondly, the anisotropic reflectance of the surface can potentially carry information about the surface, which may be additional and complementary to that obtained by nadir looking satellite sensors in different spatial, spectral and temporal domains. In either case, it is necessary to understand and model the dependence of surface reflectance on illumination and sensor geometry through development of BRDF models, both for the removal/normalization of angular effects and to retrieve surface parameters in remotely sensed data. A detailed and exhaustive review of various aspects of BRDF and its applications in data normalization and biophysical parameter retrieval is available in a special issue of Remote Sensing Reviews (Liang and Strahler, 2000).

A number of studies on modeling of surface BRDF and its use in normalizing multi-date remotely sensed data to a common geometry have been carried out using NOAA-AVHRR data (Chopping 2000, Wu et al, 1995) and ADEOS-POLDER data (Leroy and Roujean 1993, Sridhar et al, 2001). Recently, satellite sensors such as ADEOS-POLDER, EOS-MODIS, EOS-MISR etc have been launched with the specific purpose of analyzing and modeling surface BRDF properties from space borne platforms. Due to the limited angular sampling capabilities of most satellite sensors, attempts have been made to develop models with a minimum number of parameters, usually three to four parameters to model surface BRDF from satellite data. A number of empirical and semi-empirical BRDF models have been proposed to analyze multi-angular data sets generated from satellite data. In semi-empirical models, the surface BRDF is modeled as a weighted sum of trigonometric functions of illumination and viewing angles, which are derived from physical approximations and have some physical meaning. A good and comprehensive review of semi-empirical models can be found in Lucht and Roujean, (2000).

The MODIS (Moderate Resolution Imaging Spectrometer) instrument on board EOS (Earth Observation System)-AM platform images the earth in 36 spectral bands including red and near infrared wavelengths, at different spatial resolutions, depending on wavelength. The swath of MODIS is 2300 km with a 110 degree FOV across track and it is capable of acquiring multi-angle measurements of angular reflectance of a fixed target due to overlap of images obtained on separate orbital passes. One of the main objectives of the EOS-MODIS programme is to provide about 40 products including LAI, BRDF etc at a spatial resolution of ~ 1km to the user, using a number of state-of-art algorithms. The detailed methodology of each product is documented in various Algorithm Theoretical Basis Documents (ATBDs).

In the MODIS BRDF product, multi-angular information generated from 16 days of geometrically registered MODIS data corrected for atmospheric effects, is used along with a semi-empirical BRDF model, to generate three BRDF model coefficients, viz., the isotropic, Ross-thick and Li-Sparse coefficients for each pixel, in seven wavelength regions, at a spatial resolution of ~ 1km (MODIS ATBD). These three model coefficients represent isotropic, volume and geometric components of radiation reflected from the target respectively, and have physical interpretation in terms of underlying surface parameters such as LAI (Leaf Area Index), leaf reflectance, soil reflectance etc. The isotropic (angle independent) term represents surface reflectance with sun at zenith and nadir view, while the volume and geometric terms represent the anisotropic contributions to surface reflectance. While semi-empirical BRDF models have been used quite widely to normalize multi-angular remotely sensed data of wide swath sensors to a common geometry (Leroy and Roujean 1993), there have been relatively few attempts to explore the inherent information content of the model coefficients (Roujean et al, 1997).

In this paper, an attempt has been made to analyze empirically the relation between MODIS BRDF model coefficients in the red and near infrared wavelengths with different land cover classes as well as LAI field measurements carried out at the Central State Farm, Suratgarh, Rajasthan, India.

2. STUDY AREA AND DATA USED

2.1 Study Area

The study area consists of parts of Western India, viz. Gujarat and Rajasthan. The area is mostly semi-arid with an average annual rainfall of 20 to 25 cms. During the month of December, the period under study, wheat was in the crown root initiation stage while mustard and gram crops were at flowering stage.

2.2 Data Used

A 10 deg by 10 deg tile MODIS BRDF product (MOD43B1 version 003) covering the study area (~1200 *1200 km) was used along with the corresponding IRS WiFS and LISS-III data. The geographical bounds of the study area are 20 deg N – 30 deg N and 69 deg E – 80 deg E. The details are given in Table1.

Table 1: Satellite sensors used in the study

S.No	Satellite/ sensor (Path/ Row)	Date of acquisition	Wave-length (nm)	Spatial resolution (m)
1	EOS/MODIS BRDF product	Dec 01-015, 01	620-670, 841-876	925.6
2	IRS-1D/WiFS (P94-R53)	14 Dec 01	620-680, 770-860	180.0
3	IRS-1D/LISS-III(P93-R50)	11 Dec 01	620-680, 770-860	23.5

3. METHODOLOGY

3.1 Extraction of BRDF Model Coefficients

As mentioned above, the MODIS BRDF product (MOD 43B1) available in HDF-EOS format in ISIN (Integerised Sinusoidal) Grid consists of three BRDF model coefficients, viz., the isotropic (fiso), Ross-Thick (fvol) and Li-Sparse (fgeo) coefficients representing the angle-independent, volume and geometric contributions to surface reflected reflectance. These coefficients are given for each of seven spectral bands and three broad bands and shape parameters representing surface anisotropy in the red and NIR wavelengths are also available in the product. The BRDF model coefficients as well as the shape parameters corresponding to red and NIR bands were extracted from the MODIS BRDF product and converted into GeoTiff format in geographic latitude-longitude coordinates using the Modis Reprojection Tool (MRT).

3.2 Comparison with IRS-1D WiFS data

The IRS-1D WiFS data of spatial resolution 188 m was resampled to ~ 1km resolution using relevant modules of ERDAS-IMAGINE software operating on SGI workstation. The degraded WiFS image was registered to MODIS image using a number of GCP's distributed throughout the image. The maximum error in the scan and pixel directions was less than a pixel in scan and pixel directions. Various land cover classes such as sand, crops (mustard), shallow water and deep water were identified on the WiFS image and corresponding three BRDF model coefficients along with three shape parameters were noted from the MODIS BRDF product for further analysis.

3.3 Field measurements of LAI

Field measurements of LAI were carried out during December 14-17, 2001 at the Central State Farm, Suratgarh using the LICOR-2000 Plant Canopy Analyser. The Central State Farm spans an area of ~ 12, 000 ha with an average field size of 250 * 250 m. The dominant crop in the rabi season is gram followed by mustard and wheat crops. For each field, measurements were carried out at four locations, and for each location six A and B readings of LICOR-2000 were taken to obtain representative LAI values for that location. The field LAI was computed as an average of LAI values of the four locations. Measurements were carried out for seven fields including mustard, gram and wheat crop. The measured LAI values ranged from 1.152 to 3.235 with combined standard deviation range of 0.198 to 0.90.

3.4 Comparison with IRS-1D LISS-III data

A sub scene (540 lines * 540 pixels) containing the Central State Farm, Suratgarh, Rajasthan farm was extracted from the IRS 1D LISS-III data and was registered to a georeferenced LISS-III scene of the same area with sub-pixel accuracy (RMSE=0.19 and 0.26 in the pixel and scan directions respectively). Using the gain and offset of the IRS LISS-III sensor along with extraterrestrial irradiance in red & NIR wavelengths and solar zenith angle, an apparent reflectance image was generated in the red & NIR wavelengths. Atmospheric path radiance effects were taken into account approximately by subtracting deep-water body reflectance at both wavelengths (~ 6.6 % in red and 5.2 % in NIR) and subsequently the NDVI image was generated. The fields where LAI measurements were carried out were delineated in the image, a linear regression relation was developed between NDVI, and field measured LAI, which is given below:

$$LAI = 3.0486 * NDVI - 0.8256 \quad (N=6,\ R^2=0.81) \qquad (1)$$

The above relation was applied to the NDVI image of the study area and a LAI image of the farm was generated. In order to compare MODIS BRDF product with the LISS-III derived LAI image, the LAI image was aggregated to MODIS spatial resolution (~ 1km). Since both the images are georeferenced to a common origin and have approximately the same spatial resolution, the three BRDF model coefficients in both red and NIR wavelengths were correlated with LAI values derived from LISS-III image. A total of 15 pixels were chosen from both images for comparison.

4. RESULTS AND DISCUSSION

4.1 MODIS-WiFS Comparison

The observed values of MODIS-BRDF model coefficients for two classes of sand and water and three classes of mustard crop as delineated from WiFS data are given below in Table 2. These values and their standard deviation in brackets represent an average of 3*3 pixels of the particular land cover class.

Table 2: Relation between MODIS BRDF model coefficients and selected land cover classes

S. No	Land cover class	fir	fin	fvr	fvn
1	sand	0.2744 (0.006)	0.352 (0.009)	0.129 (0.012)	0.187 (0.014)
2	sand	0.279 (0.006)	0.348 (0.009)	0.094 (0.012)	0.0136 (0.013)
3	Shallow water	0.052 (0.006)	0.019 (0.008)	0.019 (0.018)	Ns
4	Deep water	0.013 (0.008)	Ns	0.038 (0.025)	Ns
5	Crop (mustard)	0.092 (0.016)	0.348 (0.045)	0.097 (0.02)	0.274 (0.076)
6	Crop (mustard)	0.144 (0.026)	0.262 (0.039)	0.117 (0.02)	0.151 (0.074)
7	Crop (mustard)	0.118 (0.012)	0.326 (0.032)	0.104 (0.037)	0.204 (0.069)

In the above, fir and fin are the isotropic coefficients in red and NIR wavelengths, and fvr and fvn are the volume scattering coefficients in red and NIR wavelengths respectively, in reflectance units.

For the land cover classes considered here, the geometric scattering coefficient was found to be small and non-significant. Though the BRDF models are not designed to be applicable for the water class, it is interesting to note that shallow and deep-water exhibit small amounts of isotropic scattering in red and NIR wavelengths (~ 2 % in NIR and ~ 1 to 5 % in red). For sand classes, the isotropic coefficients are larger than the volume scattering coefficients. The fvr and fvn for sand classes are significant at both red and NIR wavelengths indicating anisotropy of reflectance behavior at both wavelengths.

In case of mustard crop, the behavior of the coefficients is as expected with fir and fvr lower than corresponding NIR values. It is seen that the anisotropy in NIR reflectance is more than that of red reflectance (0.274, 0.151 and 0.204 in NIR, 0.097, 0.117 and 0.104 in red). The observation that the volume effects on reflectance are significant in both vegetation and soils is also reported in Roujean et al (1992).

4.2 Correlation of MODIS BRDF model coefficients with LAI

The correlation matrix between MODIS BRDF model coefficients and with LAI values derived from aggregated LISS-III data of the same area is given below in Table 3.

Table 3. Correlations between MODIS BRDF model coefficients and LAI (N=15)

	LAI	fir	fvr	fgr	Fin	fvn	fgn
LAI	1						
fir	-0.50	1					
fvr	Ns	-0.89	1				
fgr	Ns	0.94	-0.85	1			
fin	-0.56	-0.94	0.72	0.94	1		
fvn	Ns	Ns	Ns	Ns	Ns	1	
fgn	-0.56	0.80	-0.63	0.93	0.91	Ns	1

In the above table, fir, fvr, fin, fvn are as previously defined. fgr and fgn represent model coefficients corresponding to geometric scattering terms in red and near infrared wavelengths respectively. The correlation coefficients listed above are significant at 95 % confidence level. Ns denotes non-significance.

The fir coefficient, which represents reflectance when both sun and sensor are at nadir, shows negative correlation with LAI in the red wavelength. The same behavior of the angle independent isotropic term in the visible band is reported in Roujean et al (1992). A significant negative correlation is also observed between LAI and fin and fgn parameters. The relatively low correlation coefficients between LAI and BRDF coefficients are probably due to many reasons: firstly, the small sample sizes (N=6) used to derive NDVI-LAI relation (equation 1) and subsequent LAI image. Secondly, the sample size for MODIS (aggregated) LISS-III comparison (N=15) was also small due to a small portion of the farm being available in LISS-III image for analysis. Low crop cover of gram and wheat in December 2001 could also be a reason for the relatively poor correlation between model coefficients and measured LAI. Significant correlations between the three BRDF model parameters are also seen in the above table indicating some redundancy in the information content of the three BRDF parameters.

This type of high correlations between the anisotropic parameters are also reported in Chopping (2000) using model parameters derived from NOAA-AVHRR data. These results are only indicative in nature, and further work including additional field observations of LAI at different times during the crop growing season is expected to shed more light on the relation between semi-empirical BRDF model parameters and LAI. The analysis of multi-date MODIS BRDF product with respect to multi date field LAI measurements carried out at the Central State Farm, Suratgarh during February will be the subject of a forthcoming paper.

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REFERENCES

Chopping, M. J., 2000. Large-scale Bidirectional Reflectance Distribution Function Retrieval over New Mexico with a Multiangular NOAA-AVHRR dataset, *Remote Sensing of Environment*, 74, pp. 163-191.

Leroy, M. and Roujean, J. L., 1993. Sun and View Angle Corrections on Reflectances derived from NOAA-AVHRR data, *IEEE Transactions on Geoscience and Remote Sensing, 32*, pp 684-697.

Liang, S. and Strahler, A. H., 2000. Land Surface Bidirectional Reflectance Distribution Function (BRDF): Recent Advances and Future Prospects, eds., *Remote Sensing Reviews,* vol 18.

Lucht, W. and Roujean, J. L., 2000. Considerations in the Parametric Modeling of BRDF and Albedo from Multiangular Satellite Sensor Observations, *Remote Sensing Reviews*, 18, pp. 343-379.

Roujean, J. L., Leroy, M. and Deschamps, P. Y., 1992. A Bidirectional Model of the Earth's Surface for the Correction of Remote Sensing Data, *Journal of Geophysical Research,* 97, D18, pp 20, 455-20, 468.

Roujean, J. L., Tanre, D., Breon, F.M. and Deuze, J.L., 1997. Retrieval of land surface parameters from airborne POLDER bi-directional reflectance distribution function during HAPEX-SAHEL, *Journal of Geophysical Research,* 102, D10, pp 11, 201-11, 218.

Sridhar, V.N., Ghosh, R. and Anjum Mahtab., 2001. Atmospheric and Angular effects on NDVI temporal profiles derived from ADEOS-POLDER data over India, *IEEE Transactions on Geoscience and Remote Sensing, 39*, pp 1099-1102.

Strahler, A. H., Wanner, W., Schaaf, C.B., Li, X., Hu, B., Muller, J. P., Lewis, P.and Barnsley, M.J., 1996. *MODIS BRDF/Albedo Product: Algorithm Theoretical Basis Document,* Version 4.0.

Wu, A., Li, Z. and Cihlar, J., 1995. Effects of land cover type and greenness on advanced very high-resolution bi-directional reflectance: Analysis and Removal, *Journal of Geophysical Research,* 100, D5, pp 9179-9192.