



# Estimation of leaf area index from PROBA/CHRIS hyperspectral, multi-angular data

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## Abstract

*Leaf Area Index (LAI) is a key structural and functional biophysical variable of the vegetated surfaces which is important in quantifying evapotranspiration rates and the energy exchange of terrestrial vegetation. Remote sensing offers a method of providing estimates of LAI through the analysis of the Bidirectional Reflectance Distribution Function (BRDF), an angular-dependent surface response. High-resolution, multi-angular and hyperspectral image data from PROBA/CHRIS (Project On-Board Autonomy/ Compact High Resolution Imaging Spectrometer) are used to estimate LAI. The retrieval of LAI is accomplished using the 1D turbid-medium canopy reflectance model, SAIL, coupled with the leaf reflectance model, PROSPECT REDUX. Look-up-tables are generated using scene-specific parameters required to invert the physically based model. Two experiments are performed to examine the contribution of multispectral versus hyperspectral reflectances (nadir direction) and single-look versus multi-look hyperspectral reflectances in deriving the LAI. Image data of the calibration/validation site at Chilbolton, Hampshire, UK are used for the inversion. In addition, ground measurements of LAI are compared with the retrieved LAI estimates. Retrieved LAI estimates using various spectral and directional sampling suggest that the spectro-directional reflectances from CHRIS provides more accurate results than their lower-resolution counterparts such as single-look and multispectral reflectances.*

**Keywords:** LAI, CHRIS, LUT, hyperspectral, SAIL

## 1. Introduction

Knowledge of spatio-temporal dynamic processes occurring in the biosphere, in particular amongst vegetated land surfaces is gaining importance in recent years. Leaf Area Index is one of the principal structural variables required to monitor the vegetation since it controls the gaseous energy and mass exchanges between the various interfaces. Remotely sensed data offer a wide range of resolutions to estimate the biophysical variables, although only recently does the increasing availability of high spectral, spatial and angular resolution provide better products, thanks to the new generation of sensors. Inverting the radiances using a Radiative Transfer (RT) model enables retrieval of the vegetation parameters (Kuusk, 1998, Weiss *et al.* 2000) with an advantage over the statistical optical indices, due to the lack of inclusion of the underlying physics (Weiss *et al.* 2000).

LAI, defined here as one half of the green leaf area per unit of ground surface area, is the key variable estimated using inversion of a widely used SAIL model. The objective of this study is to assess the estimation of LAI through the inversion of the RT model in different scenarios: spectral and directional domains. Two sets of experiments to assess the potential of CHRIS sensor in retrieving vegetation parameters are designed, including a comparison of: multispectral (MS) vs. hyperspectral (HS) nadir reflectances and single view angle (SVA) vs. multiple view angle (MVA) HS. Relative root mean square error (RMSE\*) is used as the merit function and a minimum error is searched for the closest fit to measured



data, and the corresponding biophysical variable is retrieved. Sampling strategies and merit functions to minimise the fit are analysed to achieve optimum utility of the data that provides the best estimates.

## 2. Study region and dataset

### 2.1 Chilbolton

Chilbolton, located in Hampshire, UK, is a European Space Agency (ESA) approved CHRIS test site with gentle topographic relief consisting of predominantly agricultural croplands, with few forested plantations and the River Test. The main focus is the Brockley field cultivated with spring barley. The various datasets used were obtained during the NCAVEO field campaign in 2006 organised by Dr. Ted Milton in Chilbolton. Datasets exclusively employed in this study are discussed in Sections 2.2 and 2.3.

### 2.2 Pre-processing of spaceborne CHRIS image

ESA's CHRIS is a hyperspectral sensor launched in 2005 on-board the manoeuvrable PROBA platform to enable the simultaneous acquisition of surface target radiances in five view zenith angles of  $0^\circ$ ,  $\pm 36^\circ$  and  $\pm 55^\circ$ . Spectro-directional reflectances from Mode 1 CHRIS data with 62 spectral channels, 34m spatial resolution imaged on 17<sup>th</sup> June 2006 are investigated. About 40% of the images contain cloud and cloud-shadow which restricts the spatial extent of the image used in the analysis.

Across-track and along-track noise removal are performed using simple averaging and a methodology suggested by Dr. Jeff Settle (pers. comm.), respectively. Additionally, a Principal Component Analysis based cloud and cloud-shadow masking was performed on the radiances. Atmospheric correction using 6S code (Vermote *et al.* 1997) to obtain the surface reflectances and geocorrection with an Ordnance Survey map of 1:50,000 with root mean squared error (RMSE) less than one pixel yielded the pre-processed data. A simulated MS nadir-only dataset was derived assuming the LANDSAT ETM+ sensor configuration with 4 visible bands (482,565,660 and 825nm). CHRIS nadir is retained for the SVA HS configuration. For MVA HS data, 3 VZAs are selected: nadir and  $\pm 36^\circ$ , the omission of  $\pm 55^\circ$  VZA is because the spring barley field is not imaged in these angles.

### 2.3 Field measurements

Measurements at five colour-coded, flagged regions in the Brockley field (namely BKBR, BKGR, BKRR, BKWR and BKYR) were taken at 50m intervals. An ASDFieldSpec PRO was used to obtain canopy spectral measurements in Brockley on 15<sup>th</sup> and 18<sup>th</sup> June 2006 as well as the background soil bidirectional reflectance. Ground measurements of LAI using a LAI-2000 Plant Canopy Analyser with above-ground and within-canopy exposure to calculate effective LAI (assuming random spatial distribution of leaves) were taken under near-clear skies. Additional measurements include the use of a Chlorophyll meter to estimate the leaf chlorophyll content (LCC) and the Microtops Sunphotometer to extract the contemporaneous aerosol optical thickness (AOT). Mean field measured values of LAI, LCC and AOT are 2.48 (no units), 0.0029 ( $\mu\text{g}\cdot\text{m}^{-2}$ ) and 0.157 (no units), respectively.

## 3. Methodology

### 3.1 Canopy Reflectance (CR) and Leaf Reflectance (LR) modelling

Simulated canopy reflectances using SAIL model coupled with PROSPECT REDUX for leaf properties are compared with measured CHRIS spectro-directional reflectances (Jacquemond *et al.* 1995, Verhoef 1997). The input parameters for the SAIL model are solar and CHRIS geometry and wavelengths, canopy-related parameters like LAI, leaf hemispherical reflectance and transmittance, LAD of an ellipsoidal distribution, soil reflectance and fraction of sky radiation. LAI ranges from 0.1–5.0 and is the only free variable with spherical Leaf Angle Distribution (LAD), assumption while the other parameters remain constant. PROSPECT REDUX requires 5 leaf characteristics: N (the mesophyll structure index), chlorophyll a+b content (LCC), water content, cellulose+lignin and protein contents and most of the parameter values are either used from field measurements or from previous research (Kuusk, 1997).

### 3.2 Look-up-table (LUT) technique

Using a Look-up-table (LUT) is one of the simplest methods to invert a model involving less processing time and more accuracy compared to numerical optimization and neural networks (Combal *et al.* 2000).

### 3.2.1 Spectral and directional sampling scheme

When it comes to sampling the canopy parameter space, the use of prior information about the canopy type and architecture plays a major role in avoiding unnecessary model runs (Meroni *et al.* 2004) and therefore, field measurements enabled the prior information definition to be used in each run of the CR model. Although the CHRIS data consist of 62 bands for the HS case, 6 bands are ignored due to their proximity to the gaseous absorption regions. One and three VZAs are employed for the directional sampling since the spring barley field is not imaged in the  $\pm 55^\circ$ .

### 3.2.2 Inversion of CR model and estimation of LAI

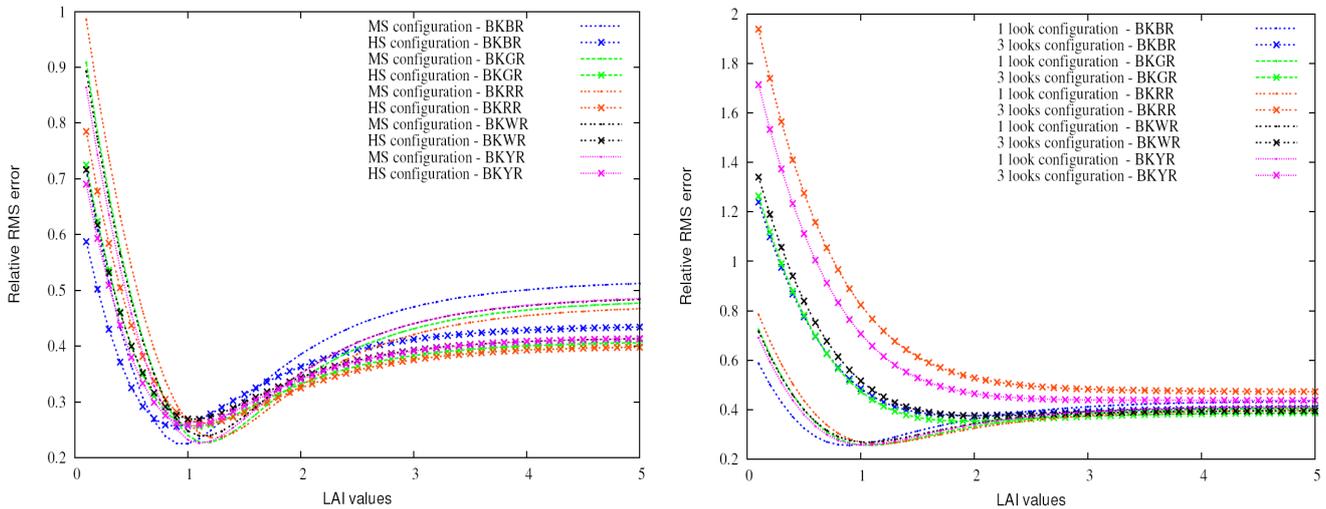
Coupled CR SAIL +PROSPECT model is run with relevant parameters and the resulting spectro-directional reflectances are stored in the LUTs for each of the described configurations. LUT are now used for the estimation of parameters by employing a merit function value which relates the measured and modelled reflectances and identifies the error associated with each parameter combination until a minimum value is arrived at. The cost function is the relative RMSE which is defined as follows:

$$RMSE^* = \sqrt{\frac{1}{n_v \times n_\lambda} \sum_{j=1}^{n_\lambda} \sum_{i=1}^{n_v} \left( \frac{R_{measij} - R_{modij}}{R_{measij}} \right)^2} \quad (1)$$

where  $RMSE^*$  is the relative RMS error,  $R_{measij}$  and  $R_{modij}$  are the measured and modelled spectro-directional reflectances,  $n_v$  and  $n_\lambda$  are the number of view angles and wavelengths considered. Once the minimum  $RMSE^*$  values are obtained for each flagged site, the corresponding LAI represents the retrieved LAI.

## 4. Results and discussion

LAI values are retrieved for each flag in the spring barley field and the results are tabulated in Table 1 and are discussed in this section, while Figures 1 (a) and (b) show the graph of the LAI values plotted against the  $RMSE^*$  values obtained, with reference to the two spectro-directional configurations.



**Figure 1:** Plot showing the relative RMSE against the LAI values for each configuration at spring barley site (a) MS versus HS nadir and (b) SVA versus MVA HS cases.

### 4.1 Comparison of different spectral and directional configurations

It can be observed from Figure 1 (a) and Table 1 that the LAI estimates from the MS and HS images are similar, but the mean LAI value is 1.06 and 1.12 for the MS and HS SVA case, respectively. This suggests that the HS measurements have a slight edge over the MS case.



Flagged sites	Measured LAI	Retrieved LAI with RMSE*		
		MS	HS SVA	HS MVA
BKBR	1.93	0.9 (0.2563)	1.0 (0.2252)	1.9 (0.3761)
BKGR	3.14	1.1 (0.2559)	1.2 (0.2275)	1.9 (0.3542)
BKRR	3.00	1.2 (0.2623)	1.2 (0.2362)	4.7 (0.4729)
BKWR	1.98	1.1 (0.2691)	1.1 (0.2392)	2.1 (0.3753)
BKYR	2.33	1.0 (0.2574)	1.1 (0.2260)	4.7 (0.4377)
Mean LAI	2.48	1.06	1.12	3.06

**Table 1:** LAI estimates for the spring barley field in Chilbolton at each flagged sites.

This small difference in the LAI estimates may be due to the fact that the MS images were derived from the HS CHRIS data with spectral averaging as close as possible to of the LANDSAT ETM+ band configuration and the number of bands is not sensitive to CR models in this case. This may be also partially due to relatively higher noise in the CHRIS image which may have been caused by poor sensor calibration and that higher the number of bands, the higher the noise influences are on the inversions.

In the case of SVA against MVA, it is certain the MVA gave LAI estimates close to the field measured LAI. This is evident from the mean LAI values of 3.06 and 2.48 for the LAI estimates and field measurements, respectively with an RMSE of 0.4 for all the flagged regions. Hence, the MVA HS data capture better structural variations than SVA. The measure of merit function and their analysis still needs to be verified as different merit functions such as absolute and normalized RMSE result in different LAI estimates (not shown here). The inclusion of  $\pm 55^\circ$  VZA would have provided more

accurate LAI estimates. Finally, the experiments are performed on a real dataset rather than a simulated test dataset and, therefore, the effect of sensor calibration and atmospheric correction should be taken into consideration.

## 6. Conclusions

This study has demonstrated the operational uses of RT models for the estimation of LAI using CHRIS data for a spring barley canopy. The advantages of MVA over SVA are clearly established; nevertheless the noisy nature of the experimental CHRIS should be considered since it assures an important step towards obtaining realistic high radiometric quality data. Modifications to the suggested approach include increasing the radiometric quality of CHRIS acquisitions, testing the LUT method for higher dimensions to retrieve leaf constituents which is underway and employing different error functions for the variable retrieval.

## Acknowledgements

This PhD is funded by the Commonwealth Scholarship Commission and British Council, UK and their help and support are appreciated. Data from the NCAVEO via the NERC Earth Observation Data Centre (NEODC) needs a special mention. Dr. Mike Barnsley is remembered for his contribution to this work.

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