An Overview of the CHRIS/PROBA Mission: A New Generation of Multi-angle Hyperspectral Remote Sensing and Its Application to Agriculture

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SUMMARY

We outline the characteristics and some potential applications of The Compact High Resolution Imaging Spectrometer/Project for On-Board Autonomy (CHRIS/PROBA) hyperspectral satellite imaging system, with specific reference to agricultural applications. The PROBA satellite was launched on 22 October 2001. Its major advantage to users is its multi-angle view capability, complementing previous generations of single nadir view sensors. The CHRIS instrument is also the first satellite mounted hyperspectral sensor to have a high spatial resolution and programmable spectral bands.

The multi-angle view capability provided by the PROBA platform has several applications, potentially improving image classification and the quantification of vegetation structure and function, as well as the validation and refinement of Bidirectional Reflectance Distribution Function (BRDF) model development for the retrieval of geophysical parameters of agricultural crops.

To evaluate the quality of the CHRIS multi-angle data, images of Iffly farm (Colly Cotton) and Auscott sites near Moree, New South Wales Australia were acquired during 2003/2004. The evaluations included Signal to Noises Ratio (S/N), radiance and reflectance values. The initial results indicate that the multi-angle image data are of good quality overall. The CHRIS/PROBA system has great potential for agricultural applications, and performs well in comparison with ground data, HyMap and Landsat data.

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1. INTRODUCTION

We present an overview of the CHRIS/PROBA campaign in Australia and the evaluation of CHRIS imagery acquired for two agricultural test sites in Australia. More detailed specifications and a description of other applications are given in Barnsley *et al.* (2004).

CHRIS/PROBA is a comparatively new satellite-based hyperspectral sensor (Barnsley *et al.* 2004). It is primarily funded by the European Space Agency (ESA) and British National Space Centre (BNSC) and was developed for land and environmental applications. The CHRIS instrument acquires data in the visible/near infrared regions of the electro-magnetic spectrum. PROBA (Programme for On–Board Autonomy) is an experimental ESA technology proving platform which enables the sensor to capture images from multiple look angles. Applications and data quality of CHRIS data are currently being evaluated by several investigators.

The CHRIS instrument is a conventional charge-coupled device array sensor intended to combine high spatial (17–20 m or 34–40 m) resolution with a multi-angle viewing capability and programmable hyperspectral channels (up to 62 spectral channels at 5-15 nm resolution between 415-1050 nm). CHRIS/PROBA (http://www.rsal.co.uk/chris) was initially intended as a short, experimental mission. Its primary objective was to test a number of innovations in platform design, principally attitude control and recovery from errors, which would enable it to operate with minimal intervention from the ground.

What differentiates CHRIS/PROBA from other Earth observation systems is its ability to acquire hyperspectral data from five different viewing angles. Such data can potentially improve image classification, the quantification of vegetation structure and function (Asner *et al*, 1998). It can also provide information about sun-target-sensor geometries from which a measure of the Bidirectional Reflectance Distribution Function (BRDF) can be derived.

The CHRIS/PROBA mission for Australian test sites focusses on agricultural applications, particularly cotton. In this paper we describe initial data acquired in 2003/2004 for two of these sites located near Moree, New South Wales, Australia.

2. INSTRUMENT AND PLATFORM SUMMARY

Barnsley *et al.* (2004) review the current status of CHRIS/PROBA Mission, including platform configuration, the CHRIS instrument, and ground activities. CHRIS has five formal modes (Table 1), for which the nominal wavelength allocations for each band and the nominal ground sampling distance (GSD) vary, with spatial resolution decreasing as spectral resolution increases. The spectral data are programmable, and the specific wavelengths for every site acquired are detailed within the Hierarchical Data Format (HDF) file in the image supplied.

Table 1: CHRIS/PROBA key Characteristics

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Band Number.	62	18	18	18	37
Band Range (nm)	406- 992	406-1003	438-1035	486-788	438-1003
Band With (nm)	6-20	6-33	6-33	6-11	6-33
Resolution at nadir (m)	34	17	17	17	17
Mean Altitude Range (km)	615 (560-670)				
Type of Orbit	Sun Synchronous				
Equator Crossing time	10.30				
Orbital Period	96.95 minutes				
Inclination	97.898 degrees				
Eccentricity	0.01				
Repeat cycles	Approximately 7 days				
Orbit Drift	< 2 degrees per year				
Bands Application	Agriculture	Water	Land	Chlorophyll	Land

Source: Sira Electro-optics (2002), CHRIS data format issue unpublished

2.1 CHRIS Angular Sampling and Viewing Geometry

One of the main issues in providing good angular sampling of the surface is the orbit in which the satellite is positioned. CHRIS/PROBA is in a sun-synchronous orbit, inclined at 97.8 degrees with an eccentricity of less than 0.0005 and mean altitude of 600 km. CHRIS acquires a set of up to five images during each acquisition with look angles of $+55^{o}$ $+36^{o}$, 0^{o}, -36^{o}, -55^{o}. Each angle cone assumes a circular orbit with distance to spacecraft equal to the semi-major axis of the orbit (Figure 1b). Each imaged target has an associated “fly-by” position. This is the position on the ground track when the platform zenith angle, as seen from the target, is at a minimum. This is described as the Minimum Zenith Angle (MZA), as a true nadir of zero is not normally achieved (see Barnsley *et al.* 2004). The platform acquires the images at times when the zenith angle of the platform with respect to the fly-by position is equal to a set of Fly-by Zenith Angles (FZA).

Viewing and illumination geometry are important in optical remote sensing. Viewing geometry includes the angle of incidence, angle of reflection, and the angle between the incident light and sensor, and much research has been devoted to correcting for viewing geometry (Schaaf *et al*, 2002; Shepard and Dymond, 2000; Ni and Li, 2000; Sandmeier, 2000). However, the emphasis in this work is not on quantifying the difference as a result of viewing angle, as we know this from the research that lead to the development of the above algorithms. Rather, the focus is on using this difference to aid in discrimination and in classification procedures. Less research has been devoted to the exploration and benefits of information derived from multiple view angles, something enabled by the CHRIS/PROBA mission.

The programmable band mode during image acquisition also enables researchers to distinguish different reflectance characteristic for selected wavelengths. Reflectance from the Earth's surface is almost always anisotropic, and so a single sensor view measurement of surface reflectance has only limited usefulness in terms of estimating the surface albedo, which is a critically important parameter of the surface radiation budget and, hence, the surface energy budget (Kimes *et al.* 1987; Barnsley *et al.* 1997).

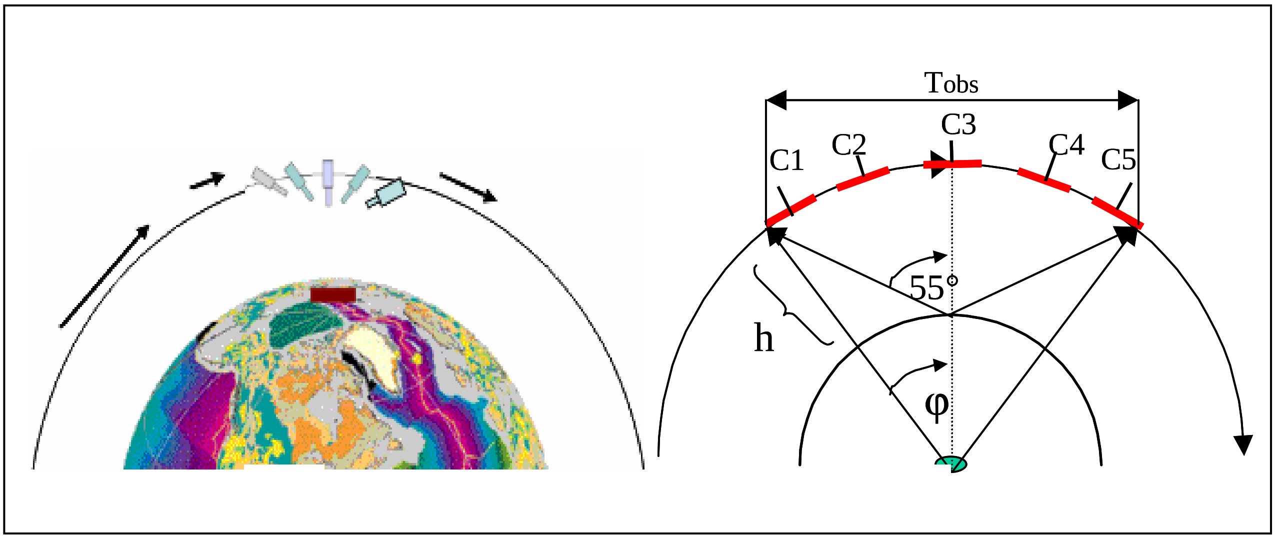

Figure 1: Chris/Proba acquisition geometry

Note: The red lines indicate image acquisitions C1 to C5 the image centre time (courtesy CHRIS data processing unit). 55° cone assume a circular orbit, h is the altitude of space craft to the ground, and φ angle of acquisition to core of Earth.

2.2 CHRIS Multi-angular Spectral Signatures

The multiple look angles of the CHRIS instrument allow us to study the BRDF for our agriculture test site. There are two main requirements for properly sampling the BRDF: (1) multiple images at a wide range of viewing and solar angles, preferably including the principal plane (PP); and (2) a ground-projected instantaneous field-of-view (GIFOV) large enough to encompass a representative sample of surface elements (Chopping et al. 2003).

Theoretically, the directional reflectance is controlled by the spatial and geometric structure of the reflecting surface, as well as by the optical properties of its component elements. The CHRIS imagery can be used to estimate the surface biophysical parameters using different techniques such as vegetation indices (conventional), red-edge position (recent developments), and BRDF model inversion (ESTEC, 1999). The different look angle will affect angular signatures. Such angular signatures of vegetation canopies can be observed as variations in reflectance with respect to the view polar angle in the principle plane, creating the 'hot-spot' effect due to the absence of shadows (Kuusk, 1983). Zhang *et al* (2002), in research on multiangle satellite data, found statistically significant differences between spectral and angular variables for different vegetation classes, and so CHRIS imagery will complement previous research on BRDF characteristics.

3. THE TEST SITE

The two test sites we describe are in the Moree region of New South Wales, Australia, at Iffly farm (Colly Cotton) ($29^0 36'$ S, $148^0 51'$ E) and Auscott ($29^0 10'$ S, $149^0 34'$E) (Figure 2). Both sites are large-scale cotton farms, and the Moree region is one of the richest agricultural production areas in Australia.

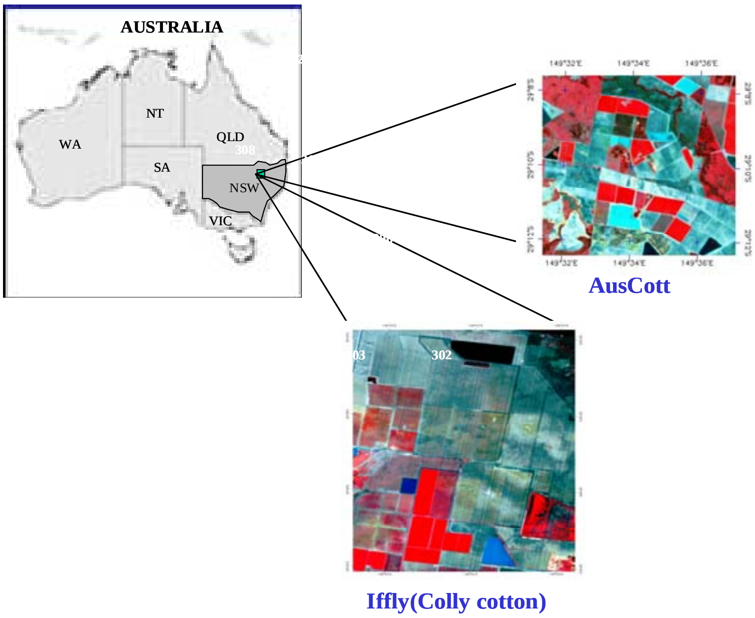

Figure : CHRIS test experiment site at Colly and Auscott, New South Wales

3.1 CHRIS Image Acquisition Status

The data collected for the Colly Cotton and Auscott sites uses Modes 1 and 3, consisting of 62 and 18 spectral channels respectively (see Table 1). Details of the Mode 3 channels are given in Table 2. Mode 3 is mostly used for land studies while Mode 1 is intended for agricultural applications.

3.2 CHRIS Data Quality

3.2.1 Raw radiance data quality

The band quality of CHRIS data can be explored through the analysis of entire scene HDF radiance data. Bands of low quality (bad bands) can be recognised by negative radiance values exceeding 500 (Ben-dor, 2003). A good quality band will present a positive radiance value. No data enhancement was performed to replace the bad band value for this data evaluation. Table 3 shows the distribution of good and bad bands for the Colly and Auscott data for selected image dates.

It is clear from the good to bad band ratios (Table 4) that the image quality for the Colly site is better than the Auscott site for the 18 band imagery. Almost half of the total bands for the

Auscott site in the 18 band data were bad. However, the 62 band image for both sites gives reasonable quality in terms of the total number of bad bands.

Table 2: The land surface bands for CHRIS/PROBA

Band	Min λ (nm)	Max λ (nm)	Mid λ (nm)	Width (nm)
L1	436.441	448.591	442.347	12.150
L2	485.272	496.849	490.983	11.577
L3	525.057	536.550	530.713	11.492
L4	545.630	558.508	551.949	12.878
L5	565.286	575.950	570.543	10.663
L6	624.796	638.842	631.732	14.046
L7	653.615	669.297	661.351	15.681
L8	669.297	680.230	674.73	10.933
L9	691.562	703.340	697.428	11.777
L10	703.340	709.424	706.333	6.084
L11	709.424	715.606	712.509	6.181
L12	734.801	748.253	741.471	13.452
L13	748.253	755.215	751.694	6.962
L14	769.362	791.705	780.421	22.342
L15	857.527	884.682	870.936	27.154
L16	884.682	903.538	894.079	18.856
L17	903.538	913.140	908.298	9.601
L18	994.991	1038.482	1016.591	43.491

Table 3: The ratio bad band and good bad of CHRIS dataset

Location	Date Acquired	No. of Bands	Bad Band		Good Band		Good/Bad Band Ratio
			Band position	Total	Band position	Total	
Colly	21-02-04	62	1,5-12	9 (14.52%)	2-4, 13-62	53 (85.48%)	7:1
	29-05-04	18	18	1 (5.55%)	1-17	17 (94.45%)	17:1
AusCott	25-03-04	62	1-11, 16,	12 (19.35%)	12-15, 17-62	50 (80.65%)	5:1
	09-04-04	18	11-18	8 (44.44%)	1-10	10 (55.55%)	2:1

Table 4: Minimum and maximum SNR of CHRIS radiance values

Location	Date	Total Bands	0deg		36deg		-36deg		55deg		-55deg	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Colly	21-02-04	62	3.3	10.6	3.4	12.6	3.1	10.3	5.2	18.3	4.8	11.4
	29-05-04	18	2.2	8.1	2.9	8.3	1.9	5.0	3.7	16.9	1.1	3.6
AusCott	25-03-04	62	2.4	8.0	2.7	8.6	1.9	7.4	2.7	8.6	2.4	8.6
	09-04-04	18	3.0	9.0	3.5	10.4	2.7	8.8	3.7	15.8	2.8	11.7

3.2.2 Signal to noise ratio

Signal to noise ratio (SNR) is one of the most important indicators of data quality in hyperspectral data. The signal to noise ration was calculated using equation 1 (Schowengerdt 1997).

$$SNR_i = \frac{\overline{DN_i}}{\sigma_i} \tag{1}$$

where SNR_i is the signal to noise ration in channel i, $\overline{DN_i}$ = Mean in Channel i, and σ_i is the standard deviation of channel i.

To evaluate the SNR at our test site, we used the radiance value of the CHRIS data set. The range of signal to noise ratio for both sites, Colly and Auscott is given in table 4.

3.2.3 Statistics of radiance/spectral value

The entire scene statistics for radiance and reflectance values for the Colly and Auscott sites for both the 62 and 18 band imagery for the five look angles shows different values for each band. The lowest value is for band 18 (1016 nm) for the 18 band image, and the highest is band 1 (442 nm). For the 62 band image the highest mean value is at bands 1 (432 nm) and 2 (446 nm), with the lowest at bands 57 (959 nm) and 58 (969 nm). Figures 3 and 4 represent radiance and reflectance value of Colly site after the data have been corrected (data 21st Feb04 and 29th May'04). A similar pattern is also obtained for the Auscott site. Clearly there are reflectance conversion problems with the CHRIS data after the 750 nm position. Fortunately this does not greatly affect vegetation indices since the use of remote sensing for agriculture application traditionally utilise wavelengths below 750 nm.

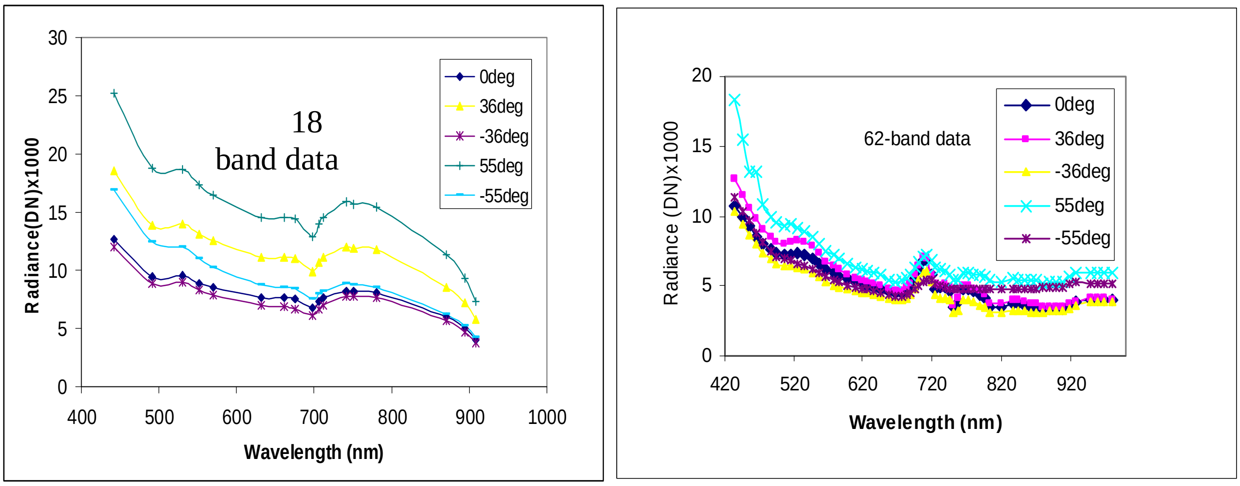

Figure 3: Mean radiance values of CHRIS dataset for Colly site at different view angle at 62 and 18 bands mode

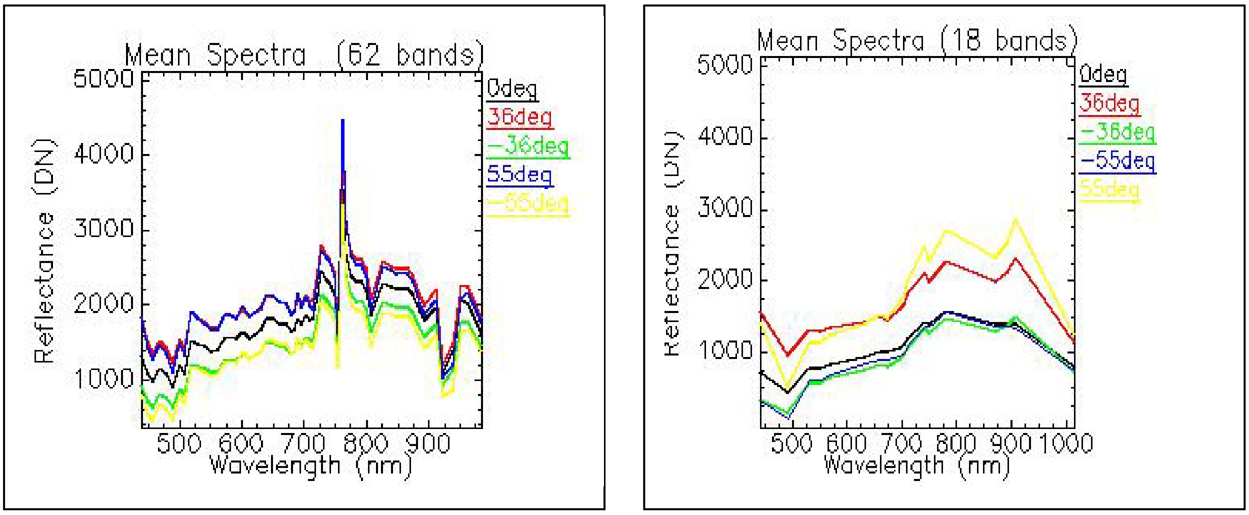

Figure 4: Mean Reflectance values of CHRIS dataset for Colly site at different view angle at 62 and 18 bands mode

3.2.4 Comparison between CHRIS and HyMap spectra

A comparison of CHRIS and Hymap data for soil, vegetation and water spectra shows that CHRIS shows a similar trend in term of reflectance value for vegetation only (Figure 5).

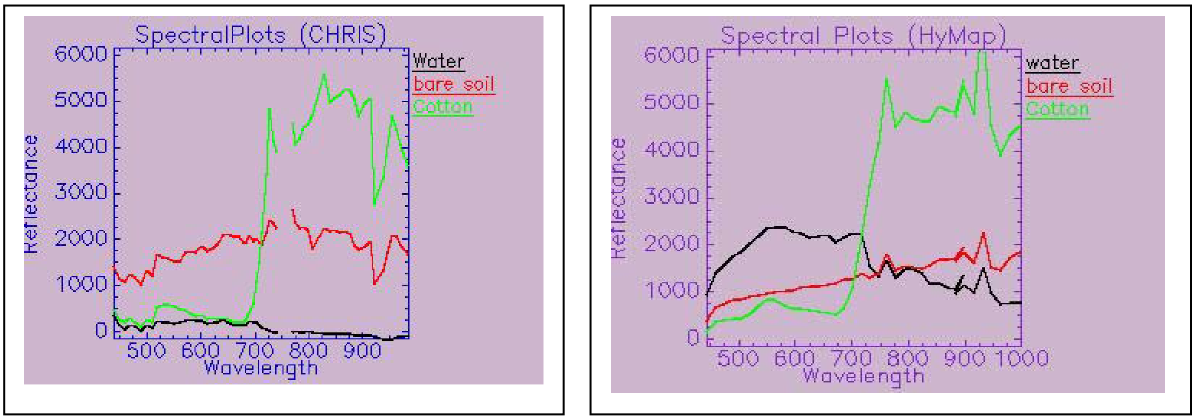

Figure 5. Cotton, soil and water spectra using (a) CHRIS and (b) HyMap sensors

3.3 Agriculture Application Issues Using CHRIS Imagery

3.3.1 The need for multi-temporal imagery

Agriculture is highly variable in time and space, and so remote sensing data must be used that can represent this. Multi temporal analysis of hyperspectral imaging system such as CHRIS provides an alternative method of obtaining phenological cycles of plants during the growing season. For vegetation studies, the calculation of multi-temporal hysteresis data for even a single vegetation species using hyperspectral imaging data can provide an opportunity to examine the suitability of measuring temporal spectral trajectories. This can provide ecologically meaningful data associated with changing vegetation growth, phenology, stress, and productivity.

In the case of our sites, multi-date CHRIS data have been acquired during growing season, but extended drought conditions have resulted in no cotton being planted.

3.3.2 Noise correction

There are two main source of noise in the CHRIS instrument: drop outs (horizontal lines) and vertical striping. This noise can be corrected using available methods such as destriping, moving average and filtering. The noise of Colly and Auscott site occurred in the western part of the image. This does not affect our investigations, as our region of interest is outside this region of noise.

3.3.3 Atmospheric correction

One of the main objectives of the CHRIS/PROBA mission for land surface studies is to use short-wave electromagnetic information to infer quantitative estimates of ground surface. This means that atmospheric correction is of extreme importance, and even more so for multi-angular data. The atmosphere influences the directional scattering signal, and this varies both temporally and spatially (Tanré, 1983). Thus, before being able to analysis the data for any application and modelling the BRDF of the surface, the effect of the atmosphere must be removed from the data.

We have implemented several atmospheric correction algorithms for our data. Atmospheric correction approaches were used such as MODTRAN4, Empirical line calibration (EL) and internal average reflectance. These were compared using HyMap and Landsat data.

3.3.4 Geometric correction

Accurate geometric registration of images is imperative for any data set, and perhaps more so for multi-angular data sets (Barnsley and Allison, 1997). There are a particular set of obstacles to the accurate co-registration which are inherent in the CHRIS data. Major activities for geometric correction for CHRIS data set still rely on ground control points (GCP). Foremost is that the data acquired at different angles have different spatial resolutions within each image, and these differ between images. The severity of misregistration on the reconstruction of the BRDF will be very dependant on the heterogeneity of the surface (Barnsley and Allison, 1997).

In the case of our test site, we used two approaches for geometric correction: GCPs and image to image registration using HyMap and Landsat images. The result of both approaches gives reasonable accuracy, with Root Mean Square (RMS) errors of 0.9 and 1.9 pixels respectively.

3.3.5 Spatial and spectral resolution

The spatial and temporal dynamics of vegetation are important information in environmental and agricultural studies. The use of broadband space-based remote sensing, for instance, is well established in agriculture for regional and global monitoring and assessment (Moran *et al.*, 1997), as is the use of spectrally more detailed information at the laboratory scale (Nagler *et al.* 2000). Current research is using airborne and ground-based hyperspectral data to scale laboratory techniques to remote platforms.

CHRIS hyperspectral data, may provide close to laboratory scale data, something currently being studied by CHRIS investigators. This could advance the use of CHRIS dataset for agriculture application.

3.3.6 BRDF retrieval and growth models

The directional reflectance properties of CHRIS/PROBA allow one to model of BRDF for most of the surface reflectance. The directional data from CHRIS/PROBA could be used both for the validation and refinement of top-of-canopy BRDF models, and for the retrieval of geophysical parameters, such as leaf area index and canopy chlorophyll content, by inversion of simplified versions of those models, or through the use of look-up table approaches applied to more sophisticated models (Barnsley *et al.* 2000). The assimilation of CHRIS data into models of plant growth, as well as more conventional red-edge position investigations and land cover studies are being investigated.

4. SUMMARY

The initial CHRIS imagery of the Colly and Auscott test sites indicates the data are useful for mapping spatial variation of land surface phenomena, and should prove valuable to agricultural application and environmental monitoring. Multi-angle images provide the possibility of using multiple images for a single crop classification to determine biophysical characteristics. Different information is provided at each angle and thus would be beneficial as an input to any process of classification or image analysis.

Multi-angular sampling of CHRIS could also provide data for the inversion of physically based vegetation canopy BRDF models. Many of the techniques could be used to derive further results. Pre-processing procedures, once improved, would greatly benefit subsequent analyses. Some key issues still remain unsolved for CHRIS current mission at our test site, for example atmospheric correction, instability in certain bands, and low signal to noise ratios.

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BIOGRAPHICAL NOTES

Sugianto works as a lecturer and researcher at Remote Sensing and GIS Program, Syiah Kuala University, Indonesia. He completed his MSc in 1997 from School of Surveying and Land Information System, Curtin University of Technology, Australia. He currently is conducting research on a Multi-angular and Multi-temporal Hyperspectral data for his PhD at School of Biological Earth and Environmental Science, The University of New South Wales, Australia

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