RETRIEVAL OF VEGETATION BIOPHYSICAL VARIABLES FROM CHRIS/PROBA DATA IN THE SPARC CAMPAING

S. Gandia, G. Fernández, J. C. García, J. Moreno

Laboratory for Earth Observation
Department of Thermodynamics. Faculty of Physics. University of Valencia.
Dr. Moliner, 50. 46100 – Burjassot Valencia (Spain)
Email: Jose.Moreno@uv.es; Soledad.Gandia@uv.es; gloriafg@uv.es; dielmo@dielmo.com

ABSTRACT

In the context of the SPARC campaign, a total of 10 different view angle images are available from CHRIS/PROBA data, all of them acquired in Mode 1 (62 spectral bands). These data make possible to test some of the algorithms developed to extract vegetation biophysical variables from high-spectral resolution data with multiangular capabilities, in the context of the SPECTRA mission. Validation of retrievals with the large dataset of ground measurements that is available in SPARC represents a unique opportunity to exploit the innovative CHRIS/PROBA data. Variability in ground measurements was evaluated by statistical techniques, according to the sampling used in the data collection. Two different approaches have been followed in the retrieval of vegetation biophysical variables. First, a large number of spectral indices have been tested with the available spectral information. The second method used is based on model inversion techniques. A combination of adapted versions of PROSPECT [1], and SAIL [2], models have been tested in forward mode, by using all available ground measurements to reproduce the top-of-canopy reflectance, and then compare these forward simulations with atmospherically corrected CHRIS data.

1. INTRODUCTION

A large amount of ground measurements were collected in the Barrax study area during the SPARC campaign, covering LAI, fCover, Leaf Chlorophyll a+b, Leaf water content and leaf biomass, together with other complementary data. All the SPARC CHRIS images have been radiometrically, geometrically and atmospherically corrected according to methods described in other papers in this conference. All the available ground measurements were cross-checked with GPS measurements. Then, for each available ground measurement, the corresponding point in each angular image was identified, and a database has been developed by putting together each ground measurement with the corresponding CHRIS measurements to facilitate the development and testing of different retrieval algorithms.

Although it was a large variability in some biophysical variables (particularly leaf chlorophyll and water contents) mean field values can be derived, and inter-fields variability is still larger than intra-field variability. The data was collected to make possible retrievals at the level of sampling unit, thus describing within field variability.

Retrievals based on spectral indices are limited in accuracy, but they allow also checking the overall consistency in database content.

Large discrepancies in model simulations versus CHRIS data must be understood before a model inversion strategy is applied. Moreover, multi-step techniques seem to be required to decouple the different information in a consistent manner and to determine simultaneously all the biophysical variables with reasonable values for all of them. Leaf structure and dry matter content seem to be critical factors when accounting for multiangular variations, due to the coupling of leaf reflectance and leaf transmittance at the canopy level.

2. VEGETATION MEASUREMENTS

During the SPARC-2003 campaign in Barrax (Spain), we have measured and studied different vegetation properties.

a. Leaf Area Index (LAI) from LAI-Licor
b. Fractional Vegetation Cover (FVC) from hemispherical photographs
c. Dry Matter content (DM)
d. Water Content (WC)
e. Chlorophyll Content (CC)

We have defined a strategy for the number of measurements from each crop that are statistically representative for biophysical parameters used in the characterisation of the different crops. We have focused our interest on the LAI, dry matter, water content and chlorophyll values, all of them inputs for PROSPECT and SAIL models to the forward simulations of the spectrum for the different crops.

2.1. Analysis of biomass and water content values

The measures of dry matter and water content were made in the traditional way. Typical range values for

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dry matter and for water content lies in the intervals (19–165) $g\ m^{-2}$ and (40–400) $g\ m^{-2}$ respectively and almost all the measured values can be found in this range except values obtained for water content from onion and garlic crops. Table 1 shows this range of values and mean values (μ) with standard deviation obtained for dry matter and water content.

Table 1. Dry mater and water content range values for crops and mean values (μ) with standard deviation (σ).

Crop	DM Range of values $(g\ m^{-2})$	DM $\mu\pm\sigma$ $(g\ m^{-2})$	WC Range of values $(g\ m^{-2})$	WC $\mu\pm\sigma$ $(g\ m^{-2})$
Corn	53.9 - 69.9	61 ± 6	165.9-189.5	180 ± 8
Alfalfa	55.4-106.1	90 ± 20	110.9-160.3	140 ± 30
Alfalfa	47.1 - 90.4	65 ± 19	105.9-142.8	126 ± 16
Potato	39.7- 46.1	43 ± 3	213.8-240.4	223 ± 15
Onion	71.4 - 81.4	83 ± 7	602.9-810.1	680 ± 70
Sugar beet	50.5 - 81.8	72 ± 11	315.1-635.6	400 ± 100
Garlic	99.8 -189.5	130 ± 30	482.1-712.1	600 ± 90

2.2. Chlorophyll content measurements: calibration procedure for a CCM-200 meter and posterior analysis

A CCM-200 (Opti-Sciences, Inc.) meter was used for chlorophyll content measurements because of the practical difficulties found on apply the chemical method to analyse a large number of samples.

CCM-200 gives a relative measure in digital counts and this fact justify the calibration procedure to obtain chlorophyll values. For the selection of the samples in order to calibrate the CCM-200 meter we have considered the chlorophyll content variability in the samples from the crops selected for in-situ data measurements (see Table 2). We took more samples of alfalfa in order to assure a good mean value because of the difficulty of making the measure with the CCM-200 due to the small size of the leaves.

Table 2. Selected samples for CCM-200 calibration procedure

Crop	Samples/Field
Alfalfa	15
Corn	11
Sugar Beet	8
Wheat	4
Garlic	4
Onion	4
Potato	4

Chlorophyll content was analysed following the methodology described by Inskeep and Bloom [3], based on the determination of the extinction coefficients of chlorophyll a (Chl a), chlorophyll b (Chl b) and total chlorophyll (Chl total) dissolved on NN-dimethylforamide (DMF). The absorptivity (A) for 647 nm and 664.5 nm wavelengths was measured, by means of a CARY-UV-Visible Spectrophotometer, what allows to calculate the contents of chlorophyll by using next equations:

$$Chl\ a = 12.70\ A_{664.5} - 2.79\ A_{647}\ \ (mg/L) \qquad (1)$$

$$Chl\ b = 20.70\ A_{647} - 4.62\ A_{664.5}\ (mg/L) \qquad (2)$$

$$Chl\ total = 17.90\ A_{647} + 8.08\ A_{664.5}\ (mg/L) \qquad (3)$$

where A is absorbance read at “i” nanometers and Chl is leaf chlorophyll content in mg/L.

We have checked the ratio Chl-b:Chl-a for all the calibration samples and we have found they lies, basically, in the typical expected range of values (between 0.2 and 0.38) and only on the case of corn crop results are outside this interval (Fig.1). This fact find justification in the particular structural characteristics observed for the corn plant compared to the rest of crops under study.

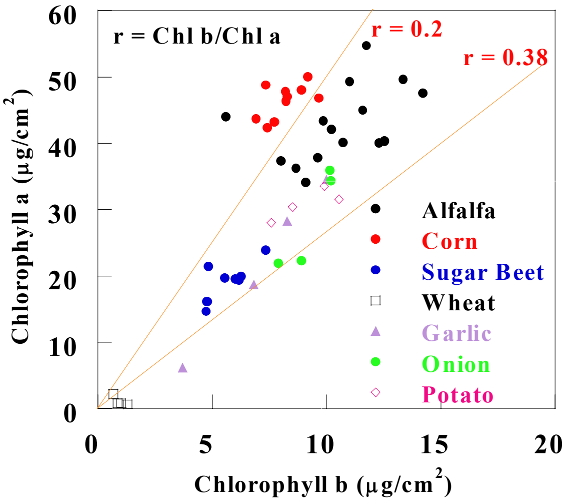

Fig. 1. Ratio Chl-b:Chl-a values for all the CCM-200 calibration samples.

By applying different calibration functions it was found best results for the logarithmic one. Next equation gives the total chlorophyll content (Chl_{ab}) from the CCM-200 Digital Counts (DC) values:

$$Chl_{ab}(\mu g\ cm^{-2}) = -12 + 34.5 * log(DC) \qquad (4)$$

Fig.2 shows results of applying this function and chlorophyll content values obtained for the different crops.

2.3. Chlorophyll in-situ measurements: analysis of the variability

The methodology applied to get the in-situ chlorophyll data consisted on measuring around 50 samples with the CCM-200 meter to characterize each Elementary Sampling Unit (ESU) previously selected for the characterisation of LAI. The measurements were taken on the leaves on the top of the plant in order to get values that could be related with satellite data.

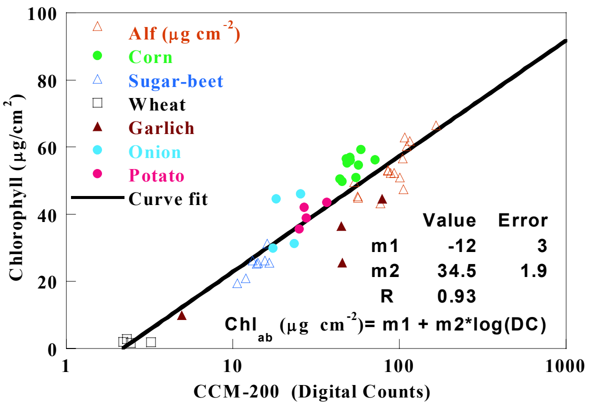

Fig.2. Relationship between CCM-200 digital counts and Chlorophyll values by means of the logarithmic calibration function.

Table 3 illustrates the different ESU's taken for each crop, the number of sampling points per ESU, mean values obtained for each ESU and for each crop with the standart deviation error.

Table 3. Chlorophyll mean values for different crops

Crop	ESU	Samples	Chlorophyll Mean Value (µg cm^{-2})	Crop Mean Values (µg cm^{-2})
Corn	C1-A1	56	48.9 ± 0.5	50.3± 0.8
	C1-A2	53	51.6 ± 0.5	
	C1-A3	55	50.4 ± 0.4	
Sugar - beet	B1-T1	44	44.9 ± 1.0	44.3 ± 1.4
	B1-T2	40	48.6 ± 0.9	
	B1-T3	42	42.5 ± 1.2	
	B1-T4	45	43.4 ± 1.0	
	B1-T5	52	38.8 ± 1.0	
	B1-T6	47	47.4 ± 0.8	
Onion	On1-B1	54	23 ± 3	18 ± 2
	On1-A1	43	23 ± 4	
	On1-B2	54	20 ± 3	
	On1-B4	49	16 ± 3	
	On1-B5	50	18 ± 3	
	On2-A1	64	22 ± 3	
	On2-A2	44	6 ± 2	
Garlic	G1-A7	53	20 ± 2	15 ± 2
	G1-A8	50	15.0 ± 1.6	
	G1-A9	49	12.5 ± 1.7	
	G1-A10	50	11.0 ± 1.6	
Potato	P1-T12	51	36.7 ± 0.7	35.6 ± 0.5
	P1-T11	50	36.0 ± 0.5	
	P1-T10	37	35.4 ± 0.8	
	P1-T9	49	34.4 ± 0.6	
Alfalfa	A9-T0	61	48.5 ± 1.2	48.5 ± 1.2

Fig. 3 shows the mean chlorophyll values for the crops selected in the experience.

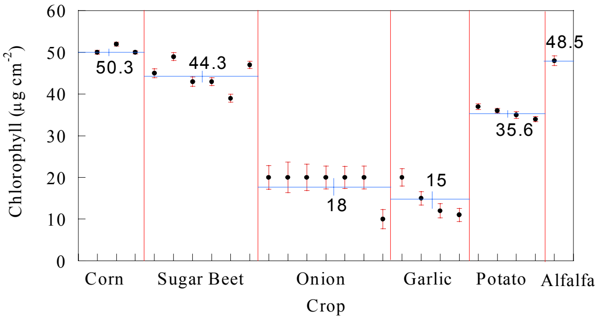

Fig. 3. Mean chlorophyll values for different crops

3. BIOPHYSICAL PARAMETERS RETRIEVALS BASED ON SPECTRAL INDICES

The first approach followed in the retrieval of vegetation biophysical variables is based on spectral indices.

Several optical indices have been reported in the literature [4][5] and have been proved to be well correlated with various vegetation parameters such as LAI, dry matter, chlorophyll concentration and more. Exhaustive comparative studies have been already carried out to asses the prediction power of different optical indices and their sensitivity to various canopy parameters and external factors [6], [7].

Retrievals based on these spectral indices (combinations of different spectral channels) are limited in accuracy, but they allow also checking the overall consistency in database content. Most significance relationships between vegetation parameters values and reflectance have been obtained from the next spectral indices:

$$\mathrm{RVI} = \frac{\mathrm{irc}}{\mathrm{r}} \qquad \text{Pearson \& Miller 1972} \quad (1)$$

$$\mathrm{NDVI} = \frac{(\mathrm{irc}-\mathrm{r})}{(\mathrm{irc}+\mathrm{r})} \qquad \text{Rouse 1974} \quad (2)$$

$$\mathrm{Ratio} = \frac{R_{674}}{R_{553}} \qquad \text{Datt 1998} \quad (3)$$

$$\frac{(R_{682}-R_{553})}{(R_{682}+R_{553})} \qquad (4)$$

$$\mathrm{Ratio} = \frac{\mathrm{TCARI}}{\mathrm{OSAVI}} \qquad \text{Miller 2002} \quad (5)$$

where

$$\mathrm{TCARI} = 3 * \left[\left(R_{700} - R_{670} \right) - 0.2 * \left(R_{700} - R_{550} \right) \left(\frac{R_{700}}{R_{670}} \right) \right]$$

$$\mathrm{OSAVI} = \left(1 + 0.16 \right) \frac{R_{800} - R_{670}}{R_{700} - R_{670} + 0.16}$$

y = -30.194 Ln(x)-18.363 Miller 2002 (6)

In addition the Depth Index and the Area Index are well correlated to chlorophyll absorption. Fig. 4 illustrates the way to obtain the Depth Index: we have measured the depth at 674 nm from a linear function fitted to 471 and 553 nm.

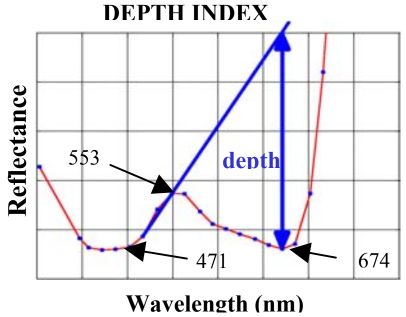

Fig. 4. Meaning of the Depth Index

The area index relates the chlorophyll absorption to the area obtained as it shows at fig. 5.

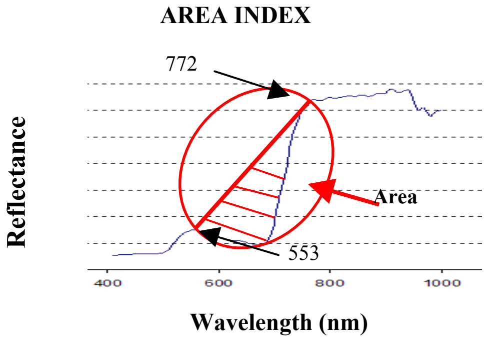

Fig. 5. Meaning of the Area Index

All these indices have been checked with our data considering, on one hand, vegetation values that were measured at leaf level so we used the Chl*LAI, DM*LAI and WC*LAI products to apply the analysis at canopy level. On the other hand, mean values per crop for vegetation parameters were checked studying reflectance correlations with the Chl*LAI, Chl*FVC, LAI*FVC and Chl*FVC*LAI products. Figs. 6 and 7 show results obtained for indices (1) and (3) using different parameters vegetation products.

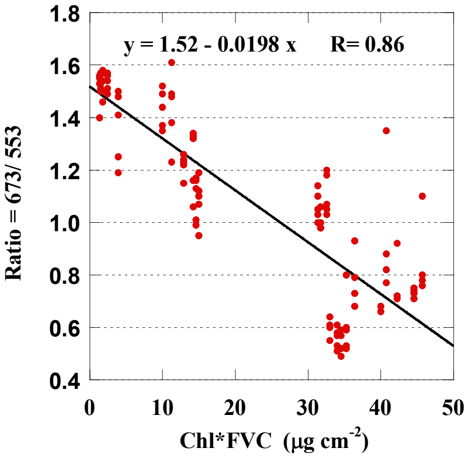

Fig. 6. Relationship between Datt proposed index and Chlorophyll-cover product

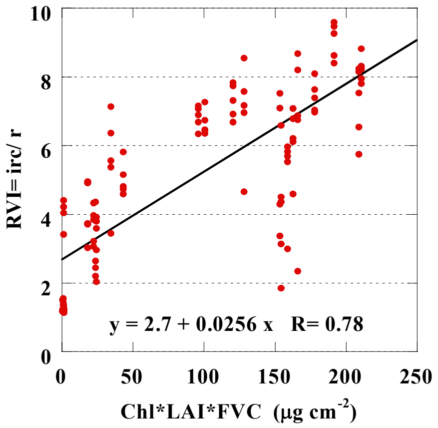

Fig. 7. Relationship between RVI index and Chlorophyll-cover-LAI product.

Correlations obtained for the different checked indices are indicated at next table where the R^2 values are reported.

Table 4. R^2 values obtained from the different spectral indices correlated with chlorophyll content.

INDEX	R²
Depth index	0.56
Area index	0.56
Ratio (553, 682)	0.46
$(R_{684}-R_{553})/(R_{684}+R_{553})$	0.64
Ratio (674, 553)	0.74
Ratio (694, 682)	0.42
RVI index	0.61

4. FORWARD MODELLING OF CANOPY REFLECTANCE

As second approach for the retrieval of vegetation biophysical variables our aim was to retrieve canopy variables by applying model-inversion techniques. But for the previous step it was necessary to test the forward modelling of canopy reflectance to compare the output data from applying the PROSPECT model at leaf level and the SAIL model at canopy level, both of them filtered for the CHRIS channels, to the acquired CHRIS spectral data from SPARC-2003 campaign (July 12th and 14th).

Figs. 8 and 9 show the CHRIS spectral mean values got, respectively, for garlic and potato and the standard deviation (σ).

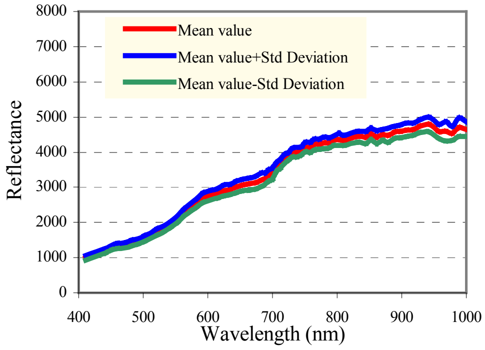

Fig. 8. Reflectance mean values and standard deviation measured for garlic crop from CHRIS data. SPARC-2003.

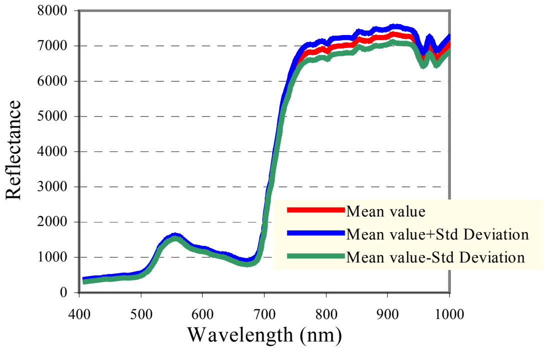

Fig. 9. Reflectance mean values and standard deviation measured for potato crop from CHRIS data. SPARC-2003.

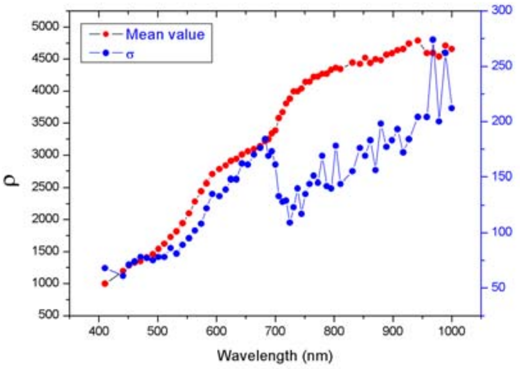

Fig. 10. Mean reflectance values (ρ) got for garlic *vs*. standard deviation (σ) from CHRIS data. SPARC-2003.

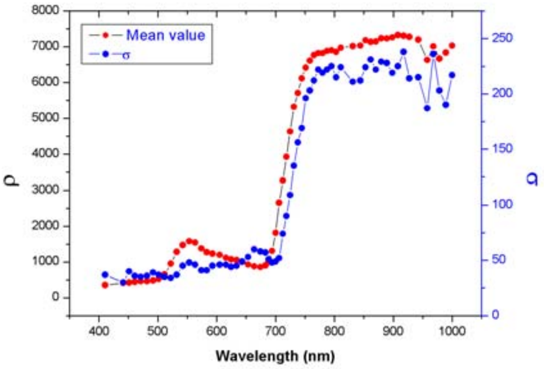

Fig. 11. Mean reflectance values (ρ) got for potato *vs*. standard deviation (σ) from CHRIS data. SPARC-2003.

LAI, chlorophyll, dry matter and water content values introduced as inputs for the forward modelling of canopy reflectance can be found in Table 5.

The input considered necessary for PROSPECT-SAIL model, in addition to in-situ biophysical data, was the structure parameter, N, related to the number of leaf layers and we checked the sensibility of the model for N values previously to start the forward modelling. Results for simulated and measured spectra from potato crop (ESU P1-T10) and for nadir view angle are illustrated at Fig. 12, where the simulated spectra with N=1.5, N=2.5 and N=5 (maximum value suggested for the structure parameter) are all lower than expected when they are compared to CHRIS spectrum, taking into account the interval error in the spectrum measured (σ).

Table 5. Biophysical parameters introduced as inputs to forward modelling of canopy reflectance

Crop	ESU	LAI	Chlorophyll Mean Value (□g cm^{-2})	Dry matter (g cm^{-2})	Water content (g cm^{-2})
Corn	C1-A1	3.84	48.9	0.006119	0.017979
	C1-A2	3.09	51.6		
	C1-A3	3.02	50.4		
Sugar - beet	B1-T1	3.85	44.9	0.007198	0.044815
	B1-T2	3.47	48.6		
	B1-T3	4.15	42.5		
	B1-T4	3.78	43.4		
	B1-T5	3.52	38.8		
	B1-T6	3.44	47.4		
Onion	On1-B1	2.36	23	0.008278	0.068112
	On1-A1	2.88	23		
	On1-B2	1.41	20		
	On1-B4	2.41	16		
	On1-B5	2.1	18		
	On2-A1	1.56	22		
	On2-A2	1.68	6		
Garlic	G1-A7	0.65	20	0.012951	0.059534
	G1-A8	0.62	15.0		
	G1-A9	0.55	12.5		
	G1-A10	0.4	11.0		
Potato	P1-T12	6.2	36.7	0.004289	0.022302
	P1-T11	5.54	36.0		
	P1-T10	5.93	35.4		
	P1-T9	5.39	34.4		
Alfalfa	A9-T0	3.84	48.5	0.006119	0.017979

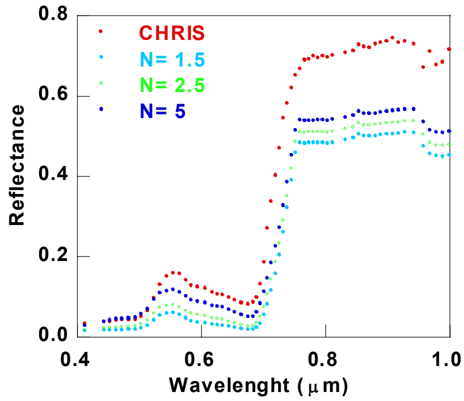

Fig. 12. Model simulations using different N values versus CHRIS data for the potato field.

Fig. 13 shows the PROSPECT + SAIL simulated spectra for garlic (ESU G1-A9) compared to CHRIS data for different view angles and their dependence with the structure parameter N. We can see that even with the largest value used of the structure parameter, we cannot reproduce the CHRIS spectrum for each view angle.

Other parameter checked in order to reproduce the spectral measurements was the dry matter, which was considered as all kind of matter that remains in leaf when we dry it.

For this reason different values of dry matter were introduced in the PROSPECT + SAIL keeping the other biophysical parameters with their real values.

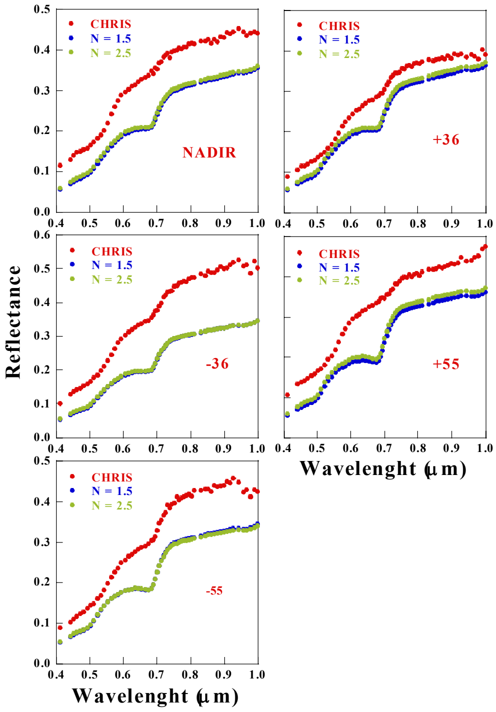

Figure 13. Simulated spectra for garlic for different structure parameter values, N, compared to CHRIS spectrum got for different view angles.

Next figure shows the simulated and measured CHRIS spectral results for potato (ESU P1-T10) for different values of dry matter (in µg cm^{-2}) using N = 2.5 as structure parameter value .

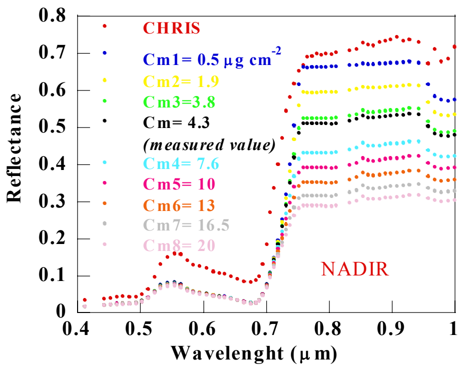

Fig. 14. Simulated and measured CHRIS spectral values for potato crop and for different values of dry matter.

As we can see in this figure, the simulated spectrum increses when dry matter decreases, and it is justified by the low absorption found for low dry matter values, but , as it can be observed, even with a DM value so small and far from the measured one (4.3 µg cm^{-2}) as 0.5 µg cm^{-2} we were not able to reproduce CHRIS spectrum.

For this reason, the next step was to check results changing LAI values. Fig. 15 and 16 show the CHRIS spectra for potato and garlic respectively for different view angles, together with:

- the simulated spectrum got from measured values of LAI and the rest of biophysical parameters and
- the simulated spectrum obtained by changing only the LAI value for one assigned value that reproduces the CHRIS spectrum

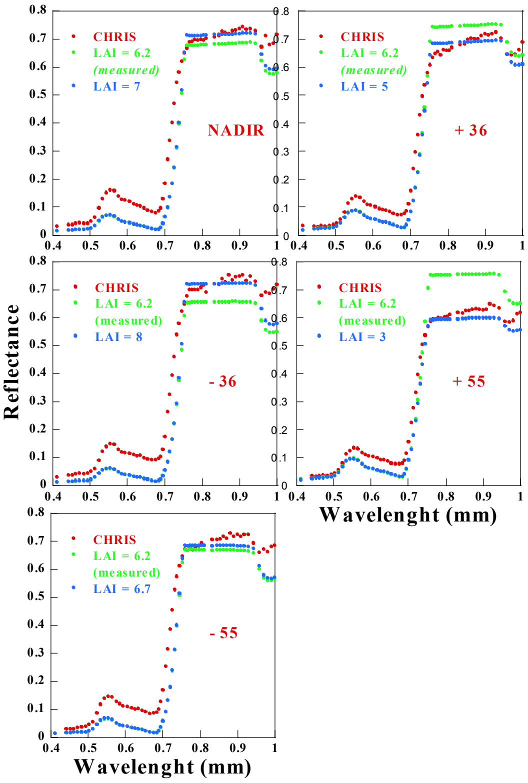

Fig.15. Simulated spectra for potato (ESU P1-T10) compared to CHRIS spectra measured for different view angles. SPARC-2003.

As we can observe in both figures, in most of cases, a change in LAI values gives similar results for simulated and measured CHIS spectral data in the infra-red spectral region. Nevertheless, for the visible range it was not posible to simulate the same spectrum with our PROSPECT+SAIL modelization.

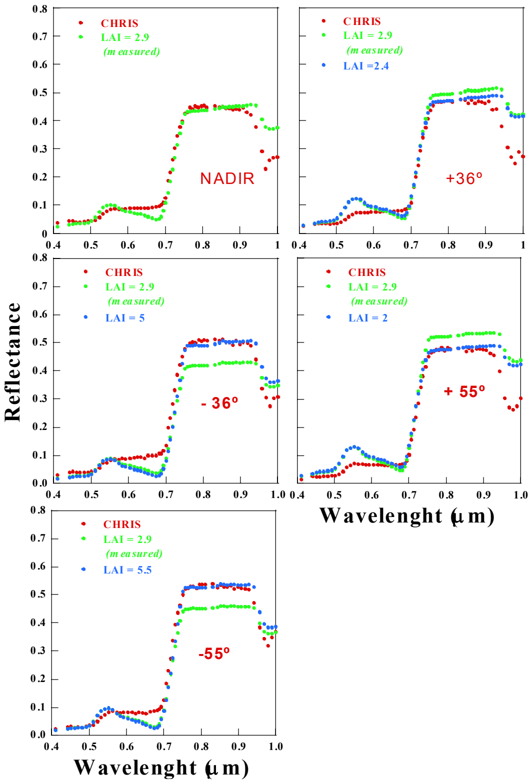

Fig.16. Simulated spectra for onion (On1-B1) compared to CHRIS measured spectra for different view angles. SPARC-2003.

Fig. 17 shows how the difference between measured and assigned LAI (ΔLAI) is related to view angle, taking as example two measuring dates, (12th July and 14th July) and two different crops (potato and onion). It seems that, in almost all the cases, negative view angles correspond to negative values of ΔLAI or, what is the same, measured LAI is smaller than the value of LAI necessary to reproduce CHRIS spectrum, while positive view angles correspond to positive values of ΔLAI. What we mean is that it seems to be a dependence in the LAI values with the view angle.

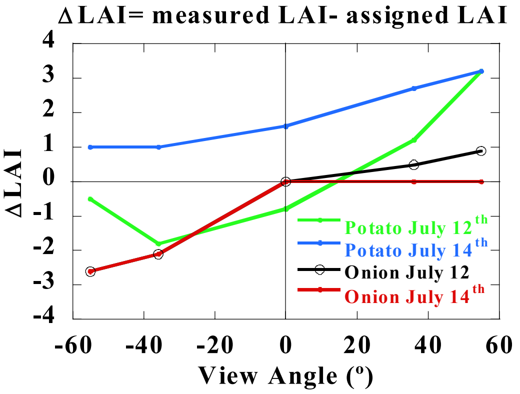

Fig. 17. Relationship between ΔLAI and view angle for two crops and two measuring dates. SPARC-03.

5. LAI AND CHLOROPHYLL RETRIEVALS

By using simple line-fitting techniques that allow to match the measured reflectance spectrum to a (simplified) reflectance model, that mostly exploit the spectral variability, some retrievals of chlorophyll and Leaf Area Index have been derived already from SPARC CHRIS data. Results are illustrated in Figures 18 and 19. First of all, it must be pointed out that the results have been derived by using individually single-angle images, with the idea of intercomparison of the results derived for each angles. Biochemicals such as chlorophyll and LAI values should be the same as derived from each angular image, and this variations in the retrievals for each angle allow to account for the angular effects. On the other hand, the overall results look quite satisfactory, taking into account the preliminary character of these retrievals.

In the case of chlorophyll retrievals, there is a significant dispersion in the scatterplot between the measured values and the retrieved ones, but there are no significant systematic effects with view angle. In the case of LAI retrievals, the dispersion in the scatterplot between the retrieved values and the measured ones is also significant, but the most significant effect is a kind of systematic dependence of LAI retrievals with viewing angle.

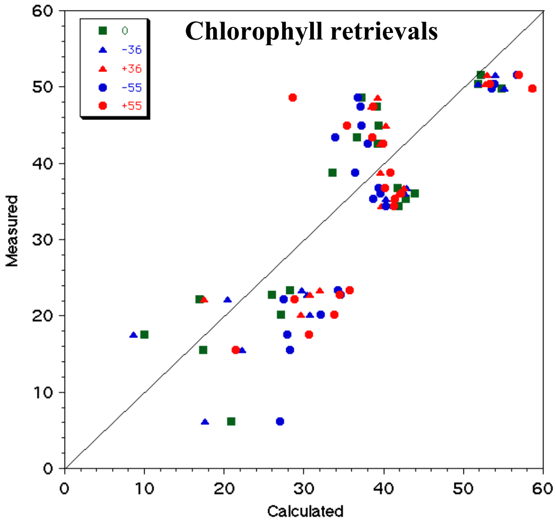

Fig. 18. Relation between measured and calculated chlorophyll values for CHRIS view angles.

To illustrate these effects in a more direct way, we have plot in Figure 20 the retrieved LAI values for each view angle versus the retrievals at nadir. They should ideally all fit at the diagonal (the 1:1 line). It is not surprising deviations from the 1:1 line, but there is a systematic variations with viewing angle that can only be explaining by a kind of LAI dependence with view angle. In fact, LAI is a kind of "effective" value, and the dependence with view angle is simply an indicator of plant structural effects not accounted for in the LAI concept.

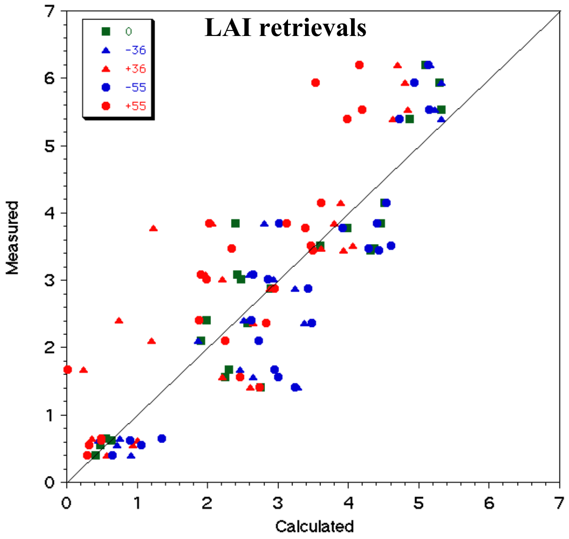

Fig. 19. Relation between measured and calculated LAI values for CHRIS view angles.

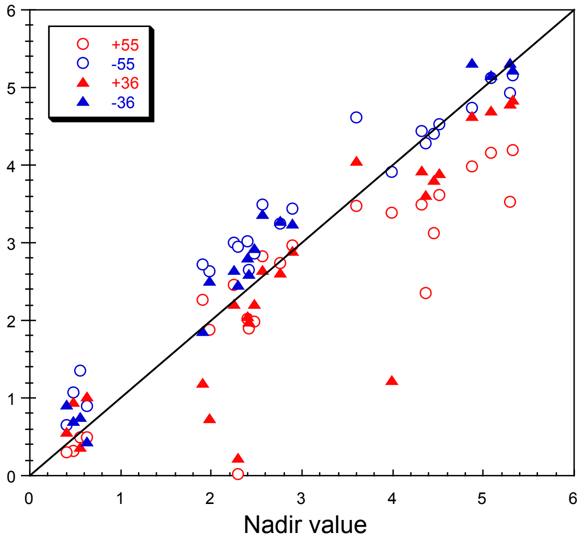

Fig. 20. Retrieved LAI values for each angle versus retrievals at nadir

Finally, it must be noted that LAI and chlorophyll maps derived from CHRIS data show some artefacts due to the presence of noises in the data that have not been perfectly removed. Retrieval algorithms that make use of channel ratios, channel differences, spectral derivatives or other mathematical combinations of CHRIS bands turn out to be quite sensitive to such coherent noises, and then a proper radiometric filtering of the images is absolutely needed before application of sophisticate retrieval algorithms.

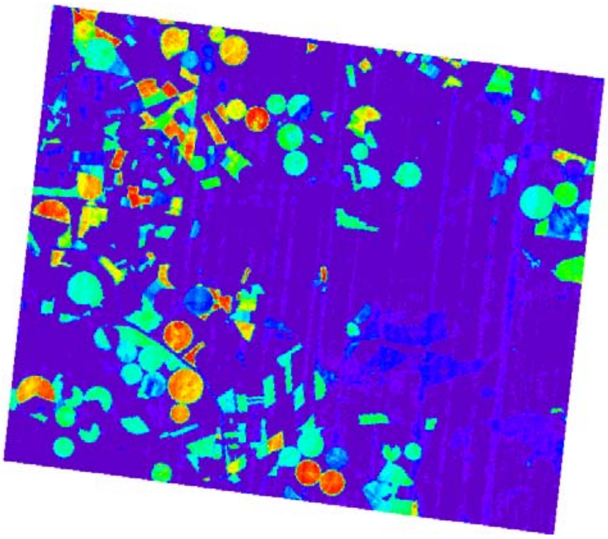

Fig. 21. LAI maps derived from CHRIS/PROBA data of 12th July 2003
(scale goes fro 0-dark blue to a 8-dark red)

6. CONCLUSIONS

CHRIS/PROBA data from the SPARC campaign have shown again the difficulties in retrieving biophysical variables when constraining models in all (most significant) inputs variables: the accuracy in the retrieval of some particular variable should not be compromised at the expenses of wrong values for other key variables.

Retrieval of biochemical contents (i.e., chlorophyll) by model-inversion approaches is limited by the capability of the model to actually represent the observed spectrum reflectance. Use of multiple views to constraint LAI compromises retrievals of biochemicals: the role of fCover and gap functions in the coupling of biochemicals and canopy structure must be accounted for. Alternative formulations allow to retrieve LAI as a function of view angle and then use such function to derive structural properties.

Significant improvements in modelling hyperspectral/ multiangular data still needed before effective inversion methods can be successfully used. Exploitation of multitemporal aspects in retrievals will be explored with the SPARC 2004 dataset.

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REFERENCES

1. Jacquemoud S. & Baret F., PROSPECT: a model of leaf optical properties spectra, *Remote Sensing of Environment*, Vol. 34, 75-91, 1990.

2. Verhoef, W., Improved modelling of multiple scattering in leaf canopy: the model SAIL++. *Proceedings of the First International Symposium on Recent advances in Quantitative Remote Sensing*, 11-20, 2002.

3. Inskeep, W.P., Bloom, P.R., Extinction coefficients of chlorophyll a and b in NN-dimethylfomramide and 80% acetone. *Plant Physiology*, Vol. 77, 483-485, 1984.

4. Le Maire, G., Towards universal broad leaf chlorophyll indices using PROSPECT simulated database and hyperspectral reflectance measurements. *Remote Sensing of Environment*, Vol. 89, 1-28, 2004.

5. Haboudane D., Miller J. R, Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture. *Remote Sensing of Environment*, Vol. 90, 337-352, 2004.

6. Baret, F., Guyot, G., Potentials and limits of vegetation indices for LAI and APAR assessment. *Remote Sensing of Environment*, Vol. 13, 95-120, 1991.

7. Broge N. H., Leblanc, E. Comparing prediction power and stability of broadband and hyperspectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density. *Remote Sensing of Environment*, Vol. 76, 156-173, 2000.