Assessment of LAI retrieval accuracy by inverting a RT model and a simple empirical model with multiangular and hyperspectral CHRIS/PROBA data from SPARC

F. Vuolo, L. Dini, G. D’Urso
Dept. Agricultural Engineering and Agronomy
University of Naples Federico II, Italy
Aim:

Retrieval of canopy parameters (in particular LAI) from E.O. data for:
- calculation of crop transpiration and soil evaporation (P-M approach)
- soil water balance simulations (input forcing)

Present objective:

Assessment of retrieval accuracy by using:
- RT models and empirical approaches (i.e. veget. indexes)
- multi-angular and/or super spectral info
Bio-physical models include vegetation parameters

\[ E_p = \frac{1}{\lambda} \left( \frac{\Delta(R_{ns} - R_{nl} - G) + 87.52 \rho D_E / r_a}{\Delta + \gamma(1 + r_c / r_a)} \right) \]

\[ R_{ns} = (1 - r)S_t \]

\[ r_c = \frac{R_t}{0.5LAI} \]

\[ r_a = \frac{\ln \left( \frac{z_U - \frac{2}{3}h_c}{0.123h_c} \right) \ln \left( \frac{z_R - \frac{2}{3}h_c}{0.0123h_c} \right)}{0.168U} \]

Based on the definition of crop water requirements of F.A.O. Paper 56 (1-step approach - Penman-Monteith equation):
Outline of procedures adopted for retrieving LAI

1. **SEMI-EMPIRICAL MODEL**: CLAIR based on the WDVI (Clevers, 1989)

2. **INVERSION OF RT MODEL** PROSPECT and SAILH (Jacquemoud & Baret, 1990; Verhoef, Kuusk, 1985) **WITHOUT A-PRIORI INFORMATION**

3. **INVERSION OF RT MODEL** WITH A-PRIORI INFORMATION FROM SEMI-EMPIRICAL MODEL

4. **OPTIMAL BANDS SELECTION** ON BOTH STEPS 2 and 3
Case-study: the SPARC campaign
Barrax (Spain, July 2003-2004)
The value of $\alpha$ was estimated by using 9 and 15 field measurements for the 12th and 14th of July (SPARC2003).

The final value of $\alpha$ was taken in correspondence of the minimum error between observed and estimated LAI.
Calibration of LAI (WDVI) empirical relationship in the Barrax site

14/07
Soil line slope: 1
WDVIₜₐₛ : 64
α : 0.4

12/07
Soil line slope: 0.9
WDVIₜₐₛ : 68
α : 0.47

RMSE = 0.59

RMSE = 0.46
The empirical relationship has been verified by using 40 independent field measurements. The correlation between measured and predicted LAI, evaluated in terms of root mean square error.
Set-up of the RT model inversion

In order to calibrate the model inversion the BRDF of 39 plots were extracted from the **CHRIS/PROBA images** of the 12\textsuperscript{th} of July by taking the mean reflectance value at each angle in a window of 3x3 pixels

**PROSPECT**

- The leaf structure parameter N, the leaf chlorophyll a + b concentration Cab, the equivalent water thickness Cw and the dry matter content Cm were bounded to the existence range of the model parameters

**SAILH**

- The mean leaf inclination angle (LIDF) and the hot spot size-parameter (HOT) were bounded to the existence range of the model parameters
- A standard background reflectance value was used.
Robustness of the inversion procedure of PROSPECT SAILH models applied to synthetic data
Identification of parameters ranges for the inversion procedure (calibration step I) on image of July 12th, 2003
Using a prior information based on initial parameter set (bounded in a range close to ground measurements and reference values)
Validation on image of July 14th, (step I)

$y = 0.6895x$

$R^2 = 0.2568$

RMSE = 1.1

NO PRIOR INFORMATION ON CROP TYPE
Validation on image of July 14th, (step II)

PRIOR INFORMATION ON CROP TYPE (initial parameter set)

\[ y = 0.7833x \]

\[ R^2 = 0.8374 \]

\[ \text{RMSE} = 0.96 \]

RMSE = 0.96

Calibration

RMSE = 0.42

MEASURED LAI

ESTIMATED LAI
In order to evaluate the use of prior information and the initial parameter set in the estimation process:

LAI: 1.32

LAI PROSPECTSAILH: 3.94
Prior information: NO
Phi: 1265

LAI PROSPECTSAILH: 1.49
Initial parameter set:
Near-optimal
Phi: 640

LAI PROSPECTSAILH: 1.42
Prior information:
LAI WDVI: 2.0 (weight: 0.1)
Phi: 526
In order to evaluate the optimal spectral sampling:

A set of 14 out of 62 (CHRIS mode 1) was selected for each view direction using information based on data quality and references in visible (516, 536, 558, 579, 685 nm) in the red edge (702, 747 nm) in the near-infrared (776, 814, 883 nm)
In order to evaluate more accurately the optimal spectral sampling, the sensitivity of each observation involved in the parameter estimation process was computed.

in visible (447, 548, 568, 587, 611, 669 and 680 nm )
in the red edge (697, 709, 721, 734, 748 and 762 nm )
in the near-infrared (776, 783, 839 and 893 nm )
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimated</th>
<th>Lower limit</th>
<th>Upper limit</th>
<th>Estimated</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1,06</td>
<td>0,51</td>
<td>1,61</td>
<td>1,00</td>
<td>0,58</td>
<td>1,48</td>
</tr>
<tr>
<td>Ca+b (mgcm-2)</td>
<td>40,80</td>
<td>30,80</td>
<td>50,87</td>
<td>31,03</td>
<td>25,95</td>
<td>36,10</td>
</tr>
<tr>
<td>Cw (gcm-2)</td>
<td>0,022</td>
<td>fixed</td>
<td>0,022</td>
<td>fixed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cm (gcm-2)</td>
<td>0,004</td>
<td>0,001</td>
<td>0,006</td>
<td>0,003</td>
<td>0,001</td>
<td>0,005</td>
</tr>
<tr>
<td>LAI (m2m-2)</td>
<td>1,21</td>
<td>1,08</td>
<td>1,35</td>
<td>1,30</td>
<td>1,17</td>
<td>1,43</td>
</tr>
<tr>
<td>HOT</td>
<td>0,001</td>
<td>0</td>
<td>0,001</td>
<td>0,001</td>
<td>0</td>
<td>0,006</td>
</tr>
<tr>
<td>Esky (%)</td>
<td>0,16</td>
<td>fixed</td>
<td>0,16</td>
<td>fixed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIDF</td>
<td>45°</td>
<td></td>
<td></td>
<td>45°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Objective function value | 87,39 | 94,89 |
| Correlation Coeff.       | 0,9982 | 0,9981 |
| Iteration number         | 18    | 26    |
| Total model calls        | 262   | 375   |
| Time (sec.)              | 35,47 | 60,72 |
Alfalfa canopies from:

SPARC 2003
LAI: 1.32

SPARC 2004
LAI: 4.00
Effect of perturbation on a-priori information (initial LAI ±20%)

Initial LAI(WDVI) –20%

$y = 1.02x$

$R^2 = 0.80$

$RMSE=0.28$

NO calibration required!

Initial LAI(WDVI) +20%

$y = 1.01x$

$R^2 = 0.80$

$RMSE=0.27$
LAI map derived inverting the PROSPECT SAILH models by using CHRIS data

They were co-registered and all bands stacked in one image. Degraded to a spatial resolution of 50 m to reduce the spatial error among the five images and the inversion time.

Classified in 4 different land use in order to add a priori information based on the distribution of some canopy characteristics that can better constrain the inversion process (initial value and bounds)

14/07/2003
Conclusions

• The data presented here provide good evidence that multi-angular and hyper-spectral remote sensing approaches may have real potential for estimating LAI and other biophysical parameters of agriculture crops.

• In spite of the limitations of the model assumptions the PROSPECT SAILH produced satisfactory results for a wide range of crops.

• The incorporation of a priori information based on estimation of LAI from WDVI improves inversion results and compensates for initial assumptions of PROSPECT and SAILH models.

• It has been confirmed as in previous studies that the reduction of spectral redundancy improve results of inversion. Therefore the CHRIS/PROBA mode 3 configuration may appear optimal in heterogeneous landscapes.