Coupled Approach for Spectral/Radiometric Calibration and Surface Reflectance Retrieval from CHRIS/PROBA Data

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1. Background

- The **removal** of atmospheric effects on optical remote sensing data is needed for the best interpretation of the carried information.

- Surface reflectance retrieval affected by:
  - Atmospheric conditions (aerosols, water vapor).
  - Elevation ASL & Topography.
  - Sensor spectral and radiometric calibration.

- **Surface reflectance retrieval scheme** considering all those factors developed at Univ. Valencia.

1. Background

- Autonomous method **SCAPE-C** (Self-Contained Atmospheric Parameters Estimation, CHRIS/PROBA version) already in an operational form (IDL) for Mode 1 (land targets) and Mode 2 (water targets).
- **Land**: Atmospheric parameters and surface reflectance validated making use of SPARC & SEN2FLEX campaigns data.
- **Inland waters**: simple method estimating AOT to derive reflectance (Peña et al., Polvorinos).
- Extension to other CHRIS modes with minor modifications.

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2. **CHRIS/PROBA data over land**
   - **Algorithm description**
   - Results: validation of surface reflectance retrievals over land

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2.1 Algorithm description

In the spectral range covered by CHRIS (mode 1, 62 bands), surface reflectance retrieval conditioned by:

1. Clouds
2. Instrumental noise
3. Spectral calibration
4. Atmospheric conditions
5. Radiometric calibration

2.1 Algorithm description

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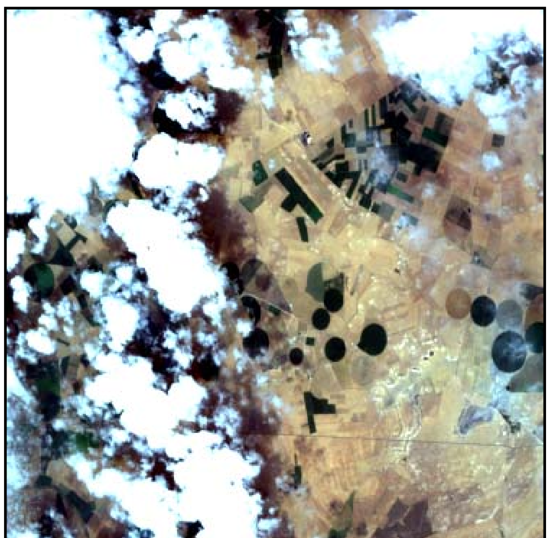
2.1 Algorithm description

1. Clouds

- L. Gómez-Chova et al. (this conference) cloud detection algorithm.
- Provides cloud probability rather than flags.
- Currently in a semi-automatic form. Automatic version under development.



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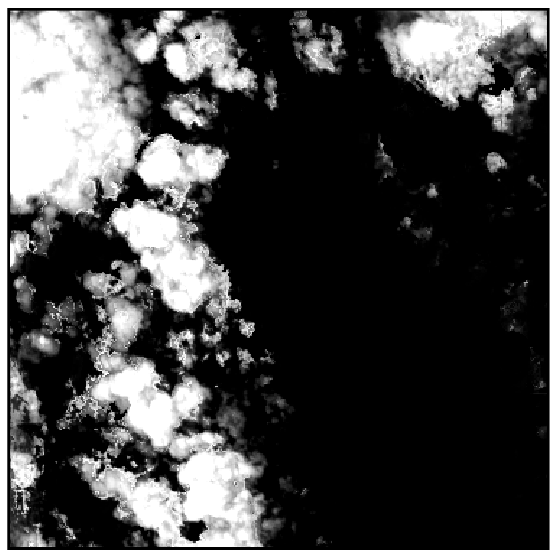

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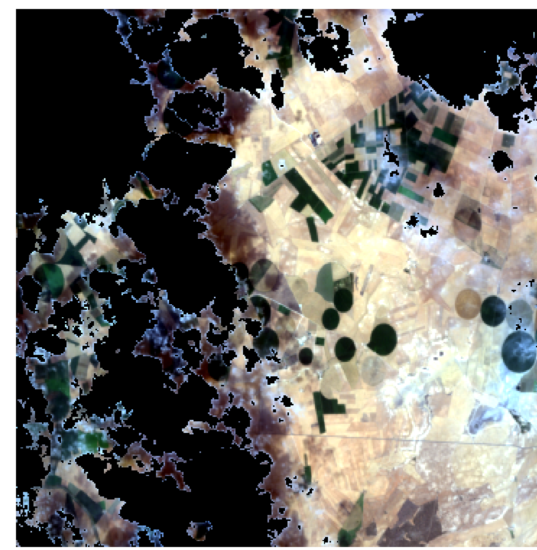

2.1 Algorithm description

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1. Clouds
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2.1 Algorithm description

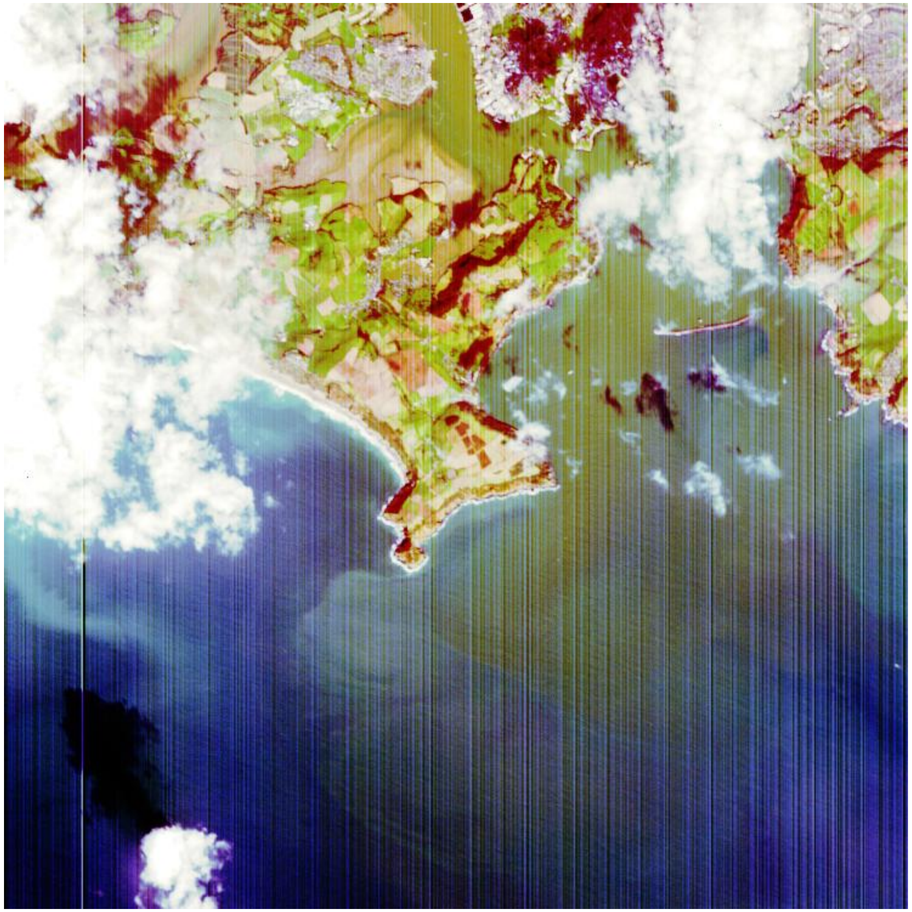
- CHRIS noise correction:
  - Drop-out noise (wrong values in odd pixels)
  - Vertical stripping (multiplicative noise pattern)
- New technique (L.Gómez-Chova et al.) to remove vertical stripping:
  - Excluding surface patterns with spatial frequencies of the same order than vertical stripping noise.
  - Using a low pass filter robust to outliers and estimating the most adequate cut-off frequency for each image band.

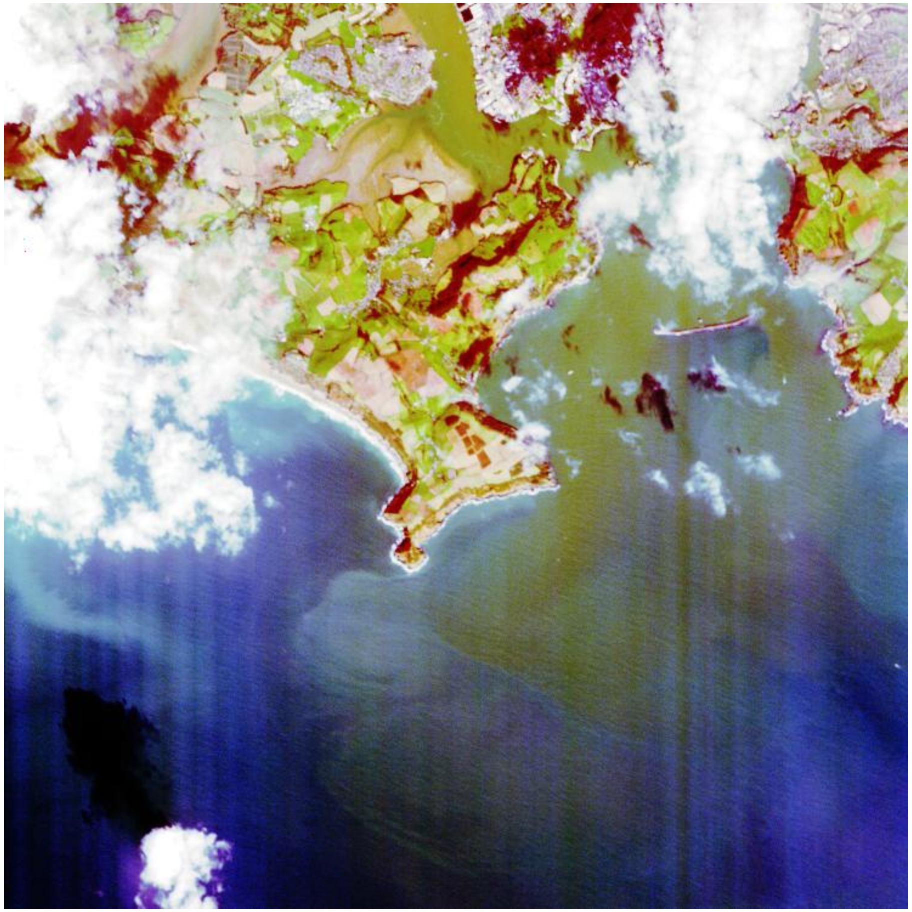
2.1 Algorithm description

2. Instrumental noise

Equalized RGB composition

Rame-Head
06-03-2003



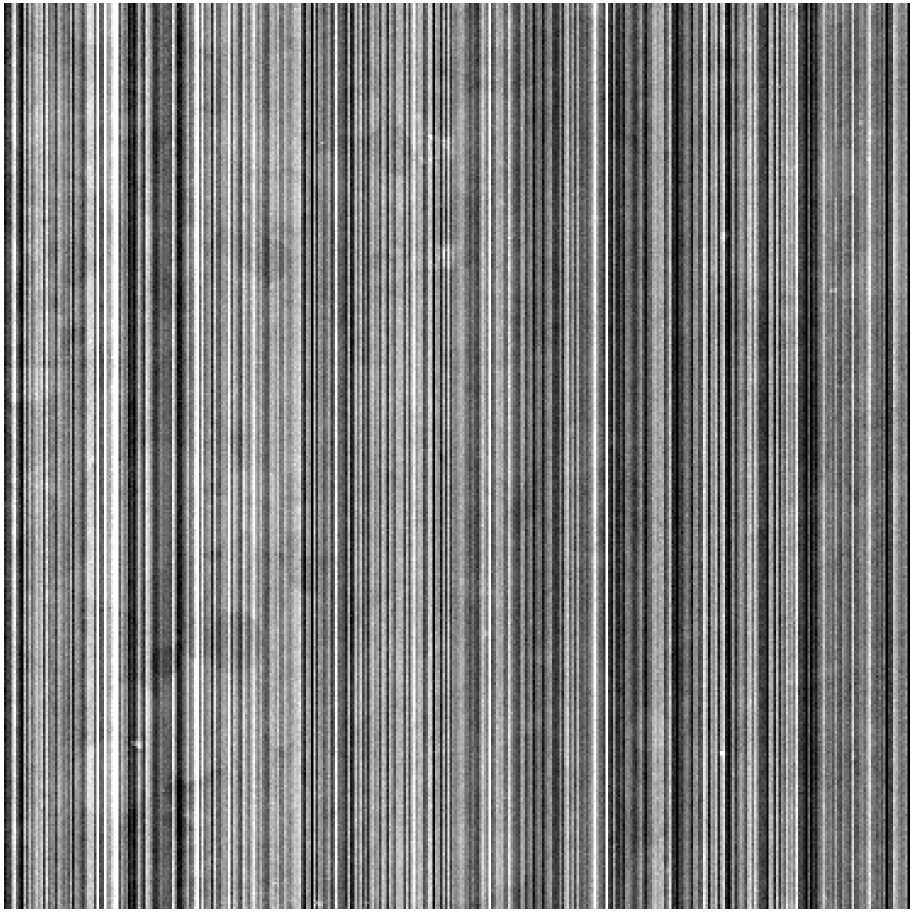


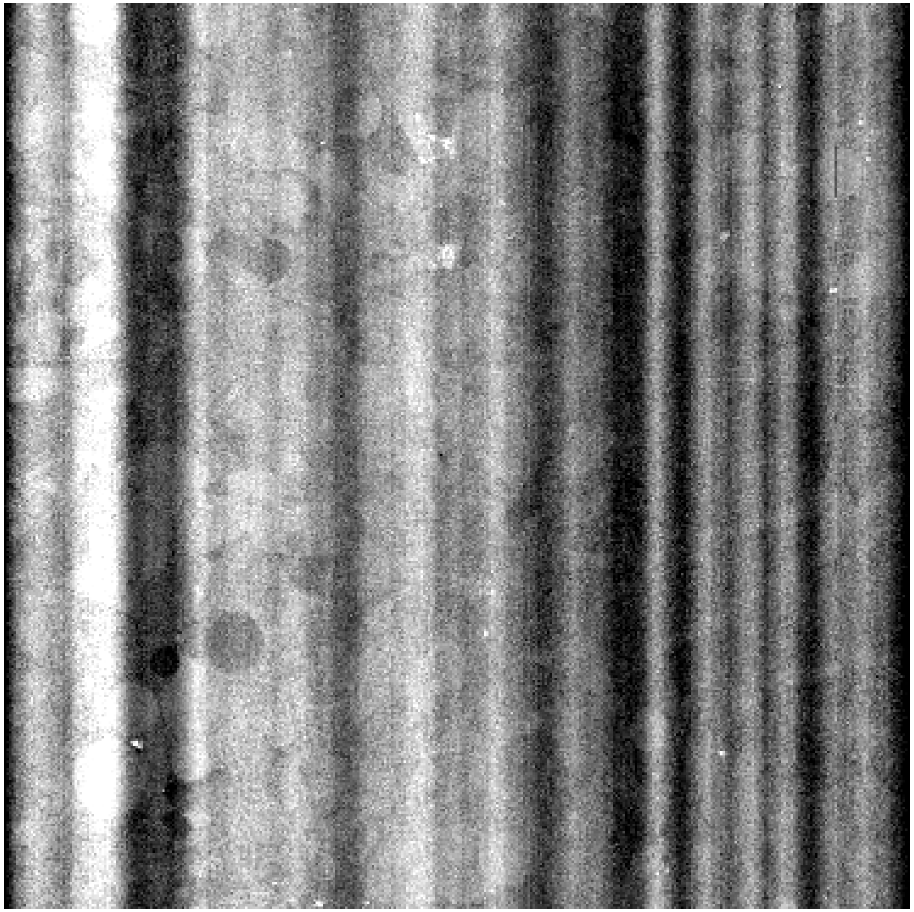
2.1 Algorithm description

2. Instrumental noise

Ratio between correlated bands (49vs50)

Barrax
05-06-2005





2.1 Algorithm description

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3. **Spectral calibration**
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2.1 Algorithm description

3. Spectral calibration

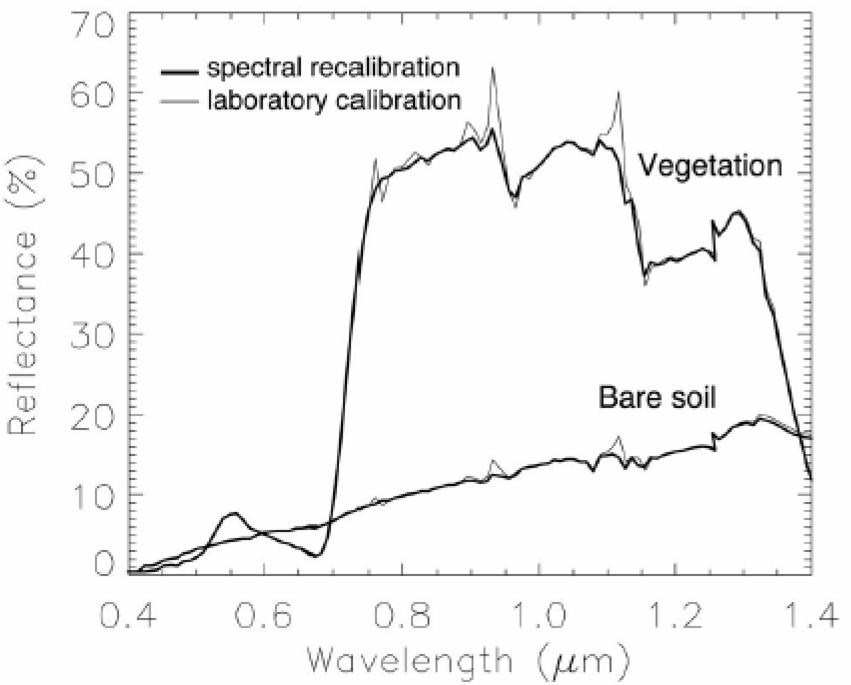
- Problems with spectral calibration:
  - Systematic spectral shifts from nominal wavelength center may occur.
  - Noticeable errors in surface reflectance close to gases' absorption bands in narrow-band hyperspectral instruments.
- Methodology to evaluate the spectral calibration of hyperspectral sensors: based on the removal of those errors.
- Used in the assessment and correction of the spectral calibration of hyperspectral instruments.

$$\rho_i = \frac{L_{\mathtt{TOA}_i} - L_{0_i}}{[(E_{\mathtt{dir}_i}\mu_s(x,y) + E_{\mathtt{dif}_i})\frac{T_i\uparrow}{\pi}] + S_i[L_{\mathtt{TOA}_i} - L_{0_i}]}$$

- Atmospheric correction → Resampling of MODTRAN4 atmospheric parameters with nominal band configuration.

$$X_i = \int_{\lambda_{0i}-2\sigma_i}^{\lambda_{0i}+2\sigma_i} X(\lambda) S_i(\lambda, \lambda_{0i}) d\lambda$$

$$S_i(\lambda, \lambda_{0i}; \delta) = \exp\left[-\left(\frac{\lambda - (\lambda_{0i} + \delta)}{C \cdot \sigma_i}\right)^2\right]$$

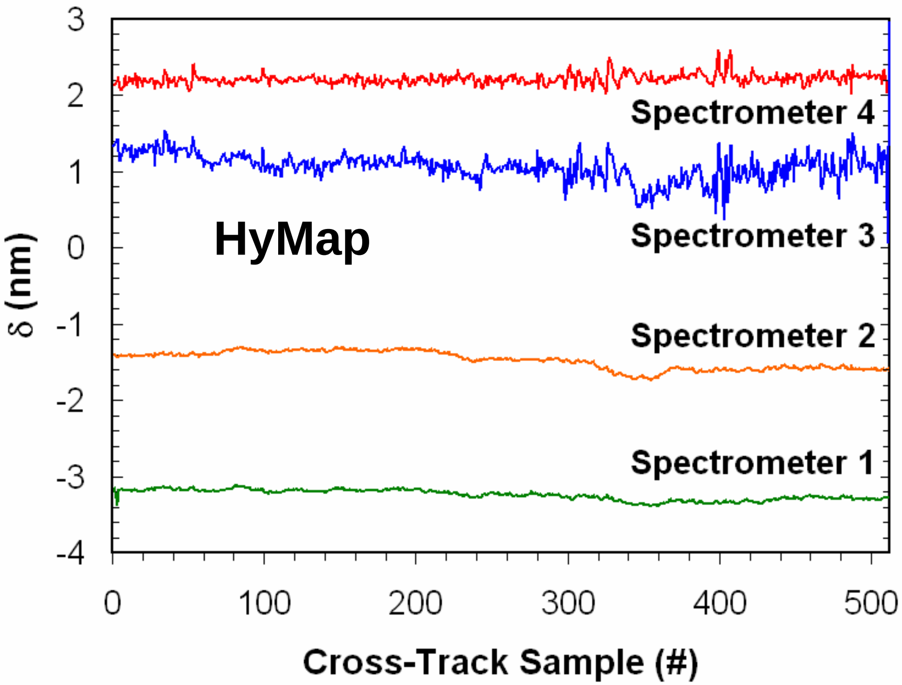


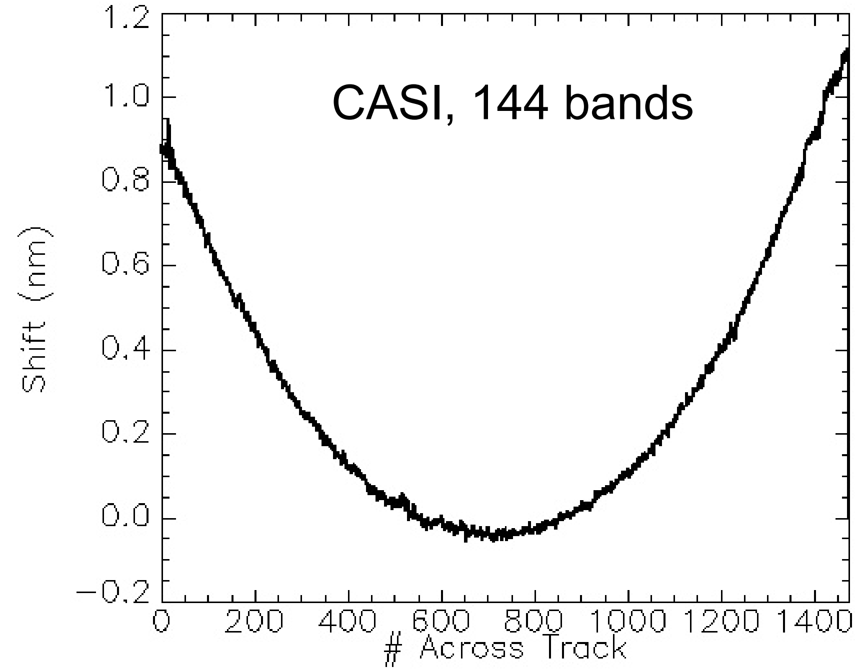
Characterization of “Smiling”

- Def. Smiling: change in the spectral response of the sensor in the across–track direction of the acquired image line.

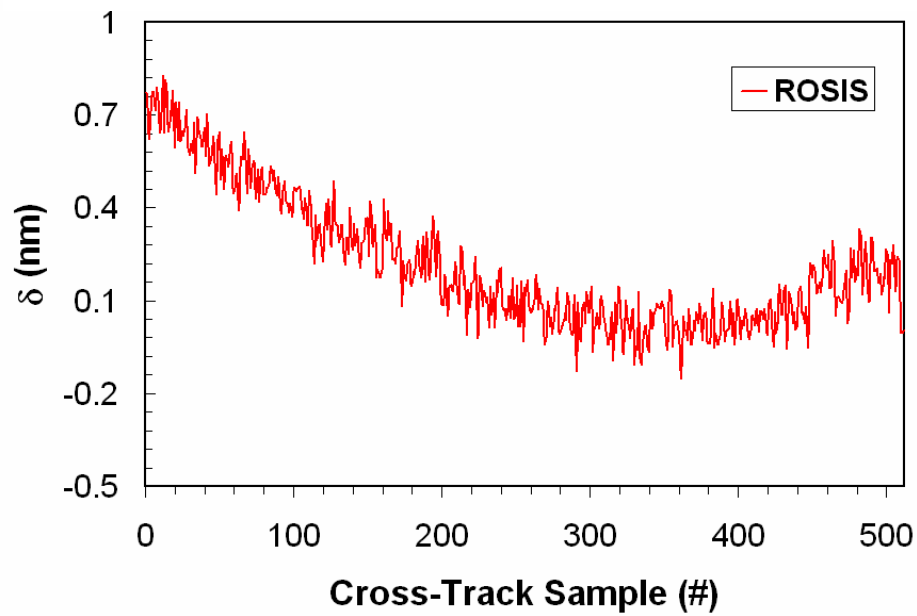
→Center wavelengths vary in the across-track direction

- Common in push-broom instruments, based on CCDs arrays.
- Atmospheric absorptions non-comparable in the across-track direction → Problem for algorithms based on absorption features.



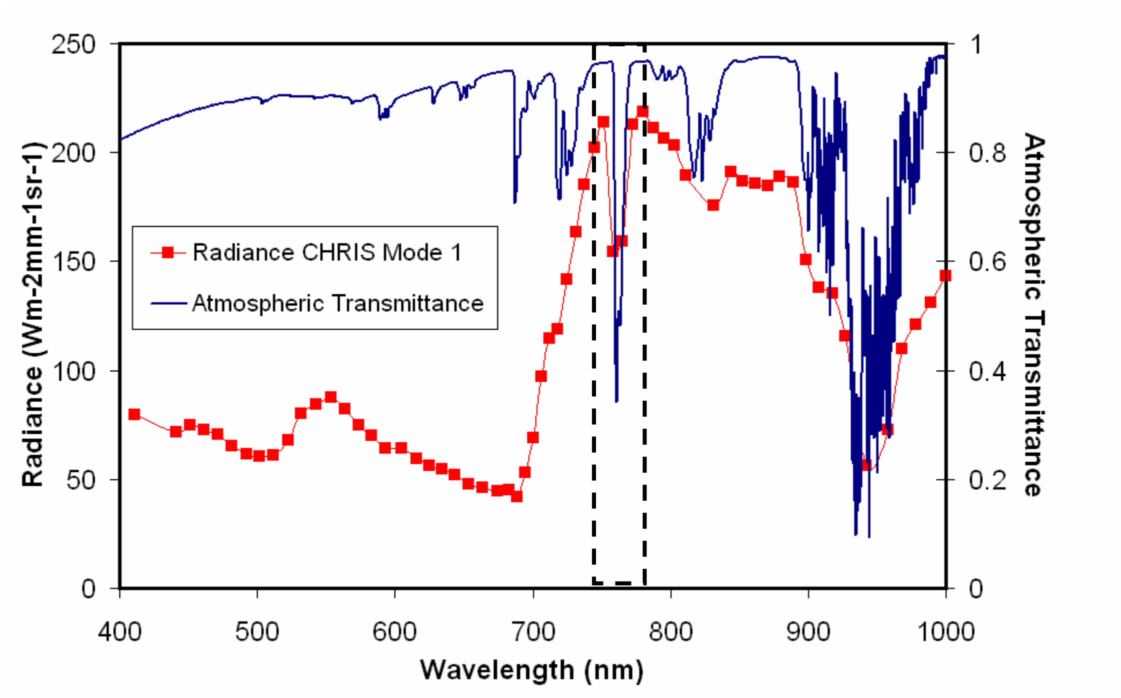


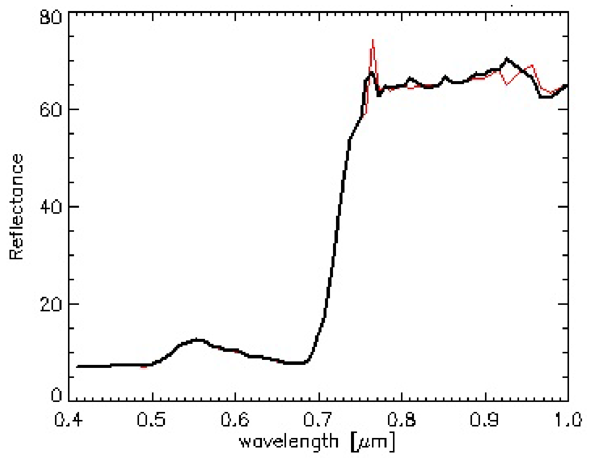
Characterization of the “Smiling” effect

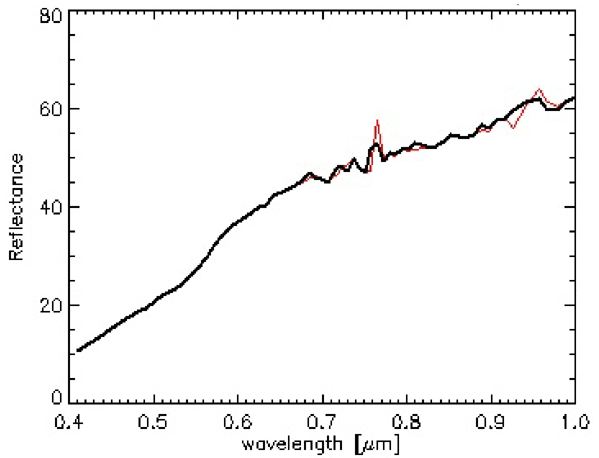


Characterization of “Smiling”

CHRIS Mode1

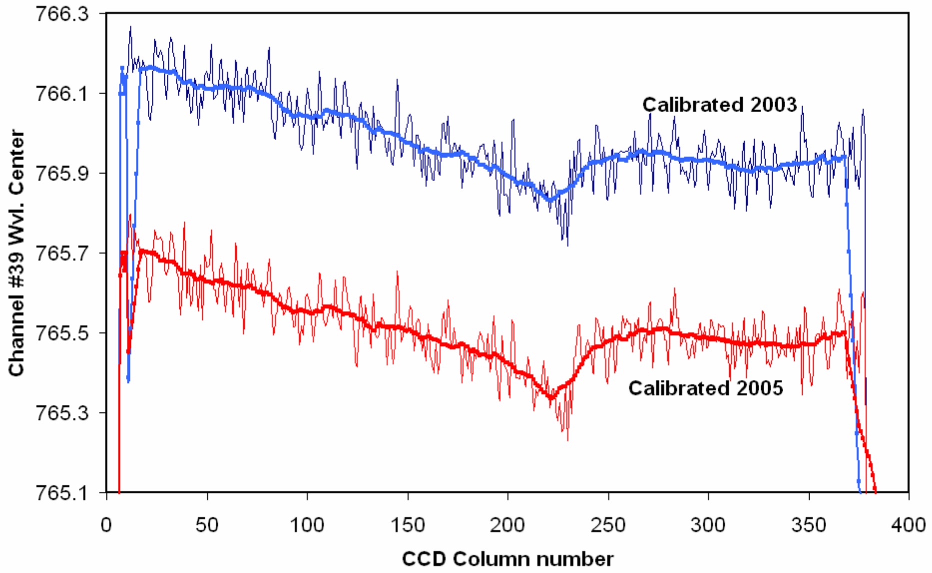




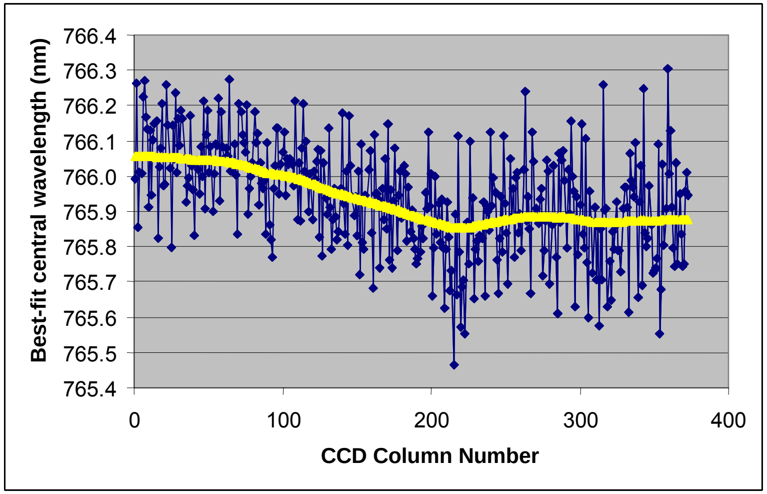


Characterization of “Smiling” - CHRIS

SCAPE-C, Univ. of Valencia



J. Settle, M. Cutter



2.1 Algorithm description

In the spectral range covered by CHRIS (mode 1, 62 bands), surface reflectance retrieval conditioned by:

1. Clouds
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4. **Atmospheric conditions**
5. Radiometric calibration

2.1 Algorithm description

4. Atmospheric conditions

- Atmospheric constituents to be considered:
  - **Aerosols** (AOT@550 nm, representing the imaged area)
  - **Water vapor** (columnar content, on a per-pixel basis)
- Algorithm designed to process hyperspectral data (CHRIS mode-1, CASI, HyMap...).
- Noise-free radiance images, cloud mask and updated spectral calibration provided by other modules.
- Atmospheric LUT generated on-line by running a modified version of MODTRAN4.

AOT retrieval

- Atmosphere is considered invariant within the CHRIS/PROBA image (swath ~15 km), while surface reflectance varies from pixel to pixel.
- The retrieval procedure consists in a multiparameter inversion of the TOA spectral radiances from a selected combination of bands in 5 reference pixels.
- With the purpose of achieving the best decoupling of atmosphere and surface contributions to TOA radiances, the 5 reference pixels are automatically selected having as much spectral contrast as possible.

2.1 Algorithm description

4. Atmospheric conditions

- Free parameters in the inversion are:
  - Aerosol Optical Thickness (550 nm).
  - Proportions of vegetation and soil in 5 reference pixels.

- Merit Function:

$$\delta^2 = \sum_{pix=1}^{5} \sum_{\lambda_i} \frac{1}{\lambda_i^2} \left[L^{SEN}|_{pix,\lambda_i} - L^{SIM}|_{pix,\lambda_i} \right]^2$$

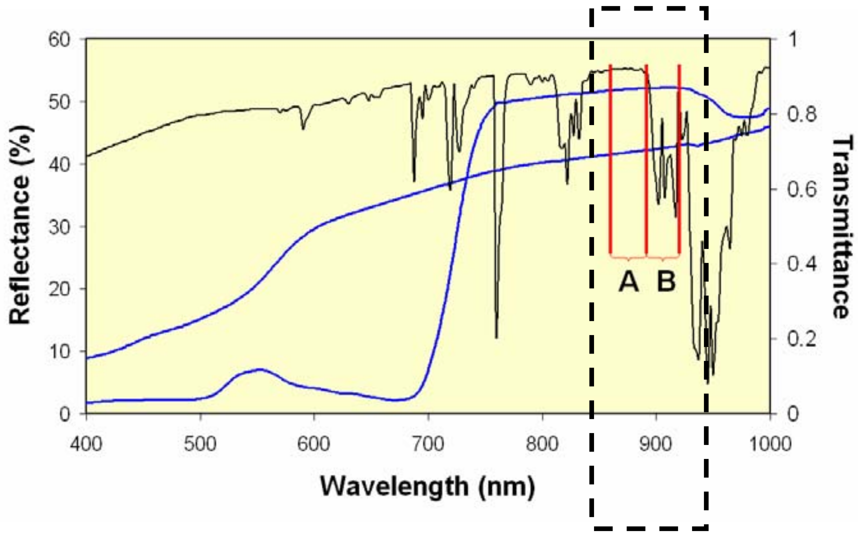
- Chi-square function is weighted by $1/\lambda^2$ to drive the inversion towards smaller wavelengths, where aerosol effects are bigger.
- Inversion by Powell Minimization Method.

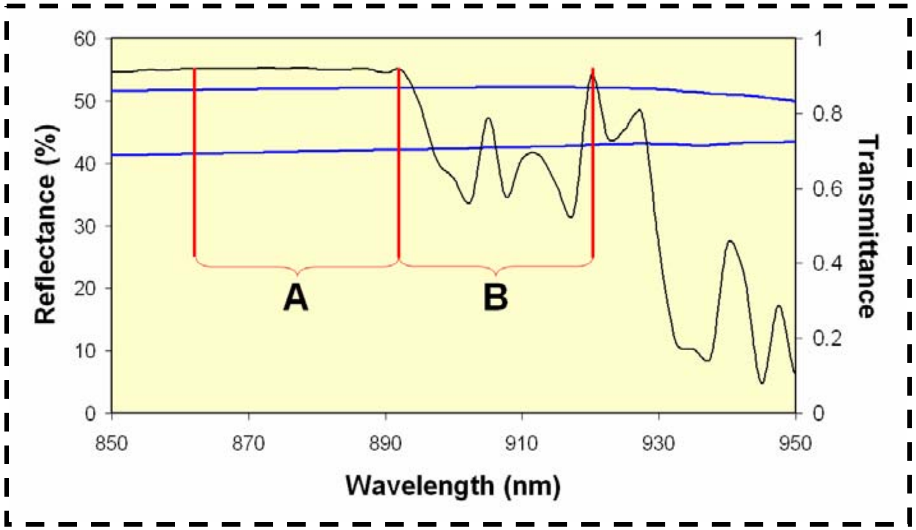
WV retrieval

- Mode-1: WV estimated on a per-pixel basis. Climatology value for other modes.
- Takes advantage of WV absorption feature at 940 nm.
- Band-fitting method, more stable and less sensitive to sensor calibration than band-ratio methods.
- Intended to minimize bias by the target brightness and spectral slope.
- WV errors due to instrumental noise can not be avoided.

2.1 Algorithm description

4. Atmospheric conditions





- Refl. assumed to be linear from 860 to 920 nm (A+B).
- WV absorption from 890 to 920 nm (B), but not from 860 to 890 nm (A).
- Refl. calculated in A and extrapolated to B.
- Radiance in A+B fitted by RT simulations varying WV content until best fit is found.

Atmosphere decoupling technique

- TOA radiance modeled assuming Lambertian reflectance for the target:

$$L_{\mathtt{TOA}} = L_0 + \frac{\left[(E_{\mathtt{dir}}\mu_s(x,y) + E_{\mathtt{dif}})\frac{\rho}{\pi}\right] T\uparrow}{1 - S\rho}$$

- Analytically invertible to retrieve $\rho_{s.}$

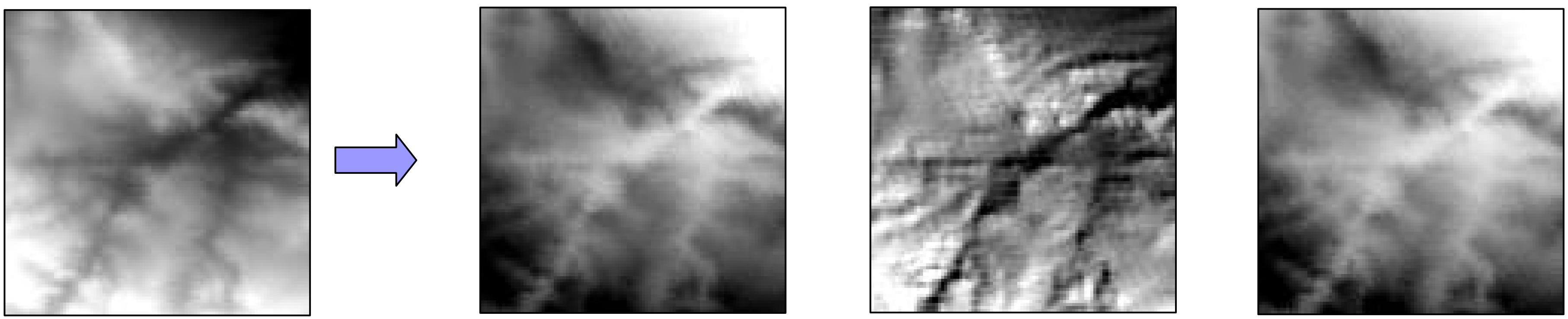
$$\rho = \frac{L_{\mathtt{TOA}} - L_0}{\left[(E_{\mathtt{dir}}\mu_s(x,y) + E_{\mathtt{dif}})\frac{T\uparrow}{\pi}\right] + S[L_{\mathtt{TOA}} - L_0]}$$

- Atmospheric reflectances and transmittances are provided by the MODTRAN4-based atmospheric LUT code, once AOT and columnar water vapor are known.

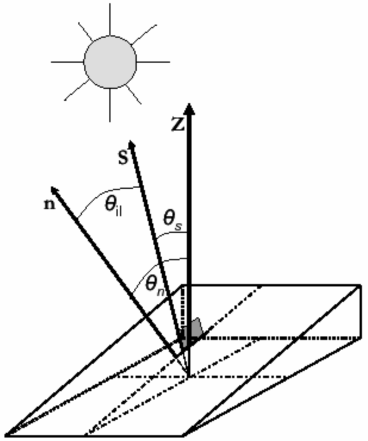
Elevation & topographic effects

- If DEM available
  - Atmospheric parameters accounting for elevation ASL on a per-pixel basis.

DEM L_0 $Edir{\cdot}\mu_{il}$ $Edif$



  - Direct and diffuse irradiance terms weighted by surface slope & orientation.



$$\mu_{\rm il} = \mathbf{n} \cdot \mathbf{S}$$

$$E^t_{\rm dif}(x,y,z) = E_{\rm dif}(z)\left[t_{\rm dir}(z)\mu_{\rm il}(x,y) + [1 - t_{\rm dir}(z)\mu_s]\frac{1+\mu_n(x,y)}{2}\right]$$

2.1 Algorithm description

4. Atmospheric conditions

Adjacency effects

- Another step in the atmospheric correction process is to eliminate the adjacency effects in the image.
- A simple formulation has been used for the blurring correction.

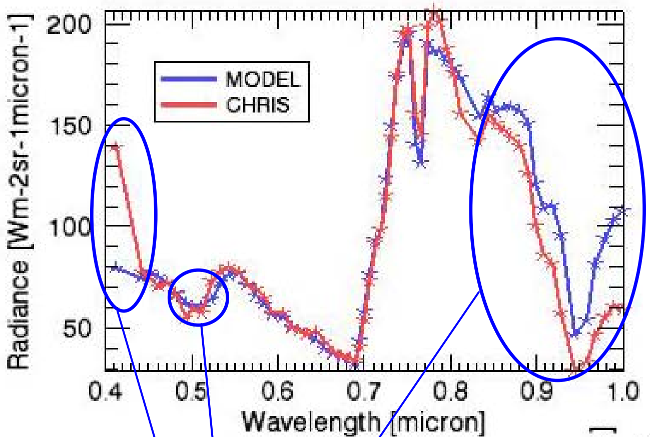
$$\rho_s = \rho_s^{blur} + \frac{t_d(\mu_v)}{e^{-\tau/\mu_v}}[\rho_s^{blur} - \bar{\rho}]$$

- Neighborhood reflectance is averaged in a 1 x 1km square (same order of aerosol coupling scale).

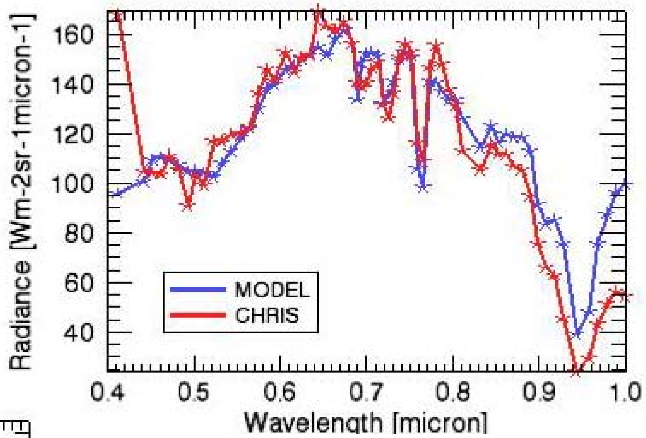
$$\bar{\rho} = \frac{1}{N^2}\sum_{i,j=1}^{N} \rho_{i,j}^{blur}, \quad N = \textit{30 CHRIS Mode-1}$$

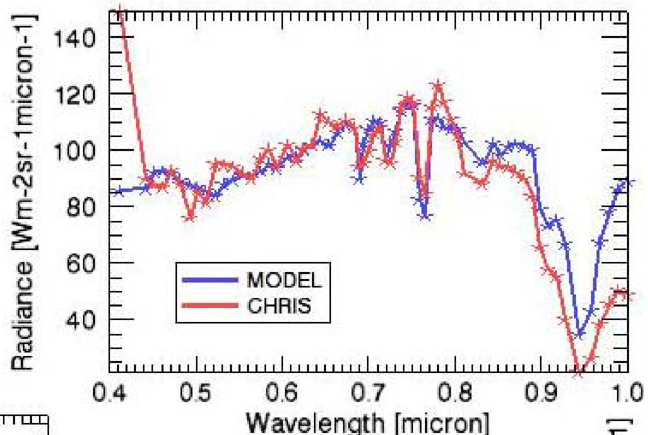
- The strength of the adjacency effect is given by the ratio of diffuse to direct ground-to-sensor transmittance.

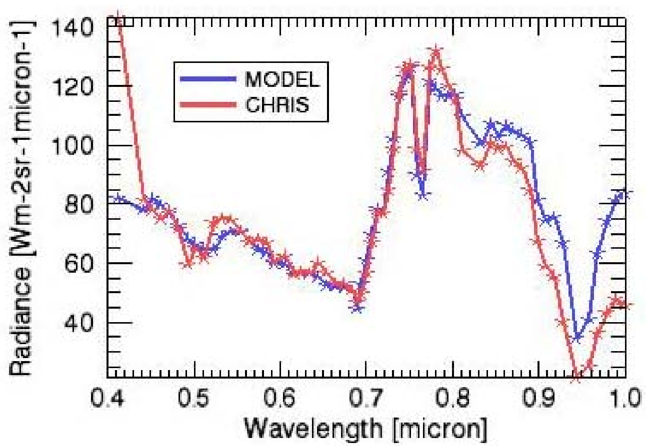
TOA Radiance Inversion FITS

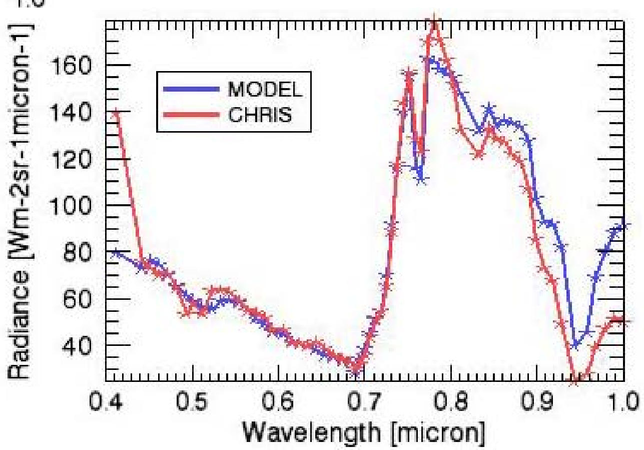


Calibration problems?

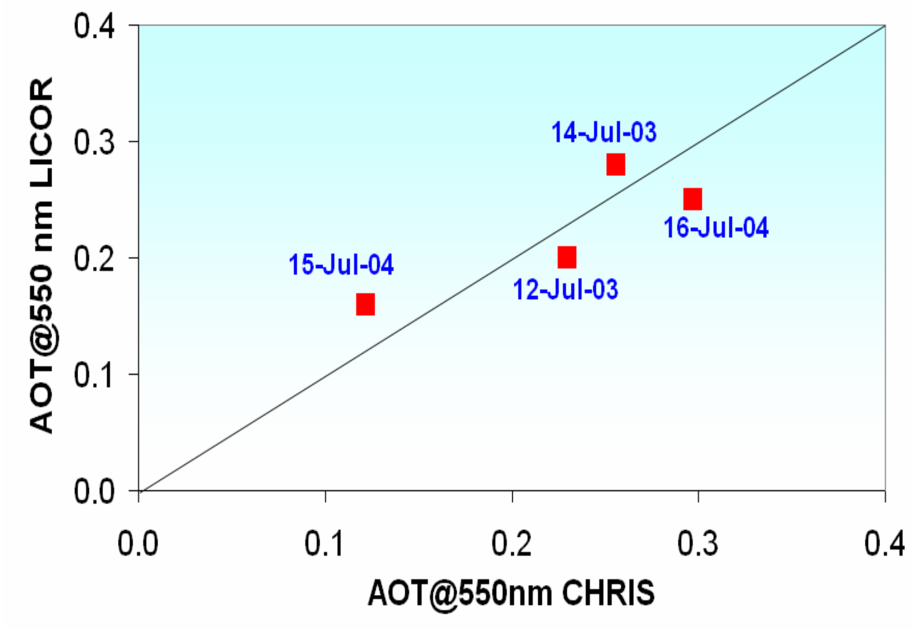


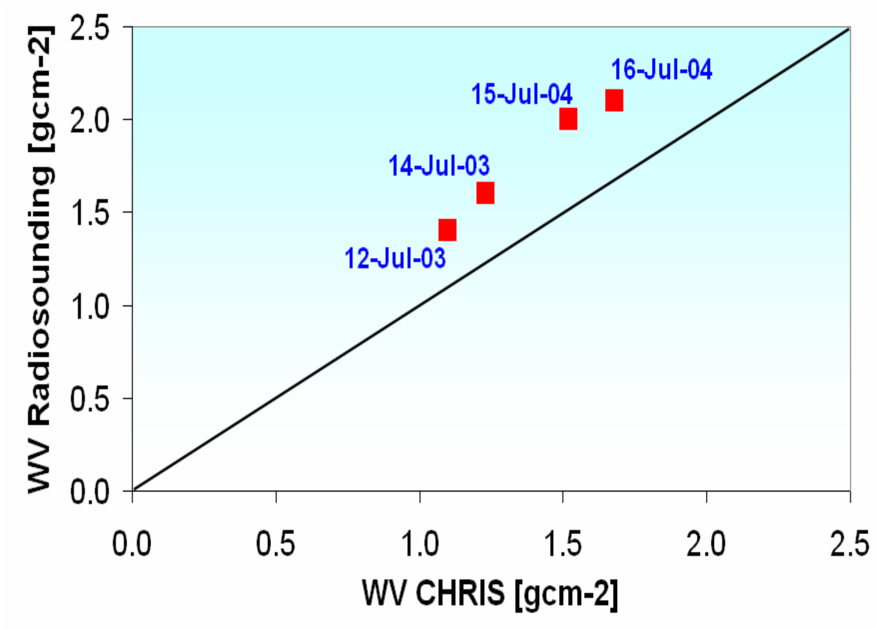






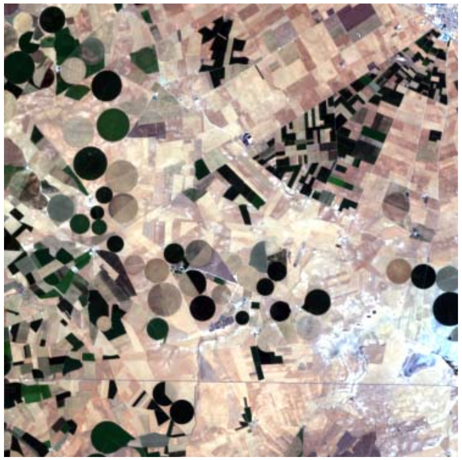
Validation of Atmospheric Products
SPARC 2003/2004



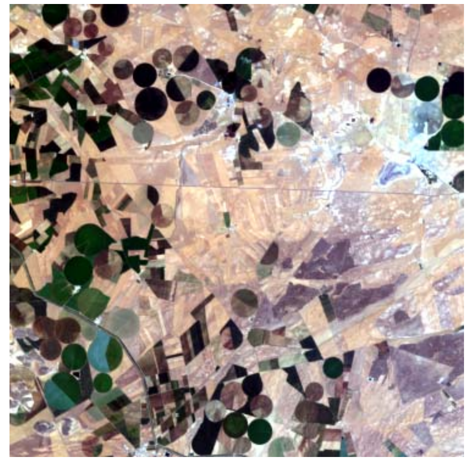


Water vapor maps
SEN2FLEX 2005

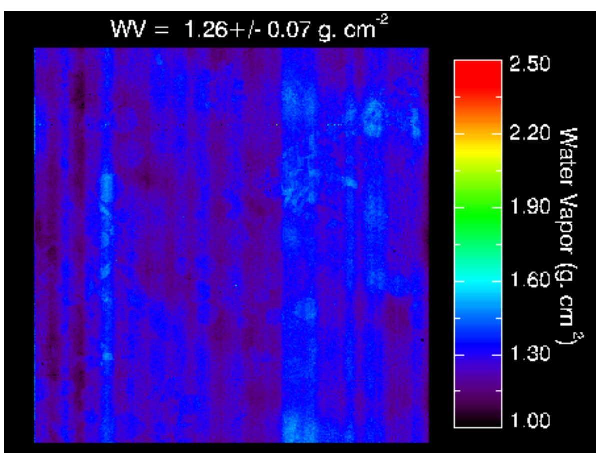
CHRIS_BR_050718_5776_41_*

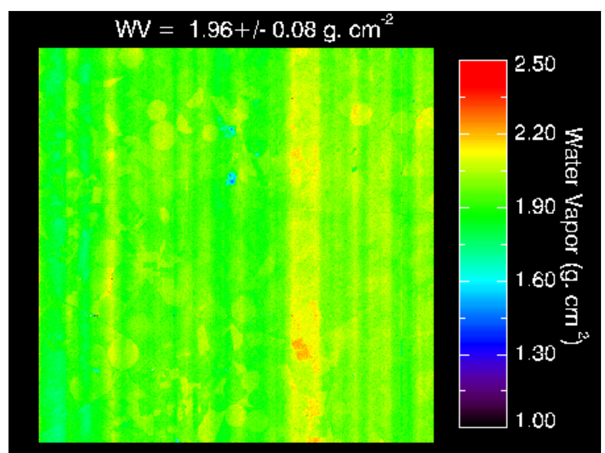


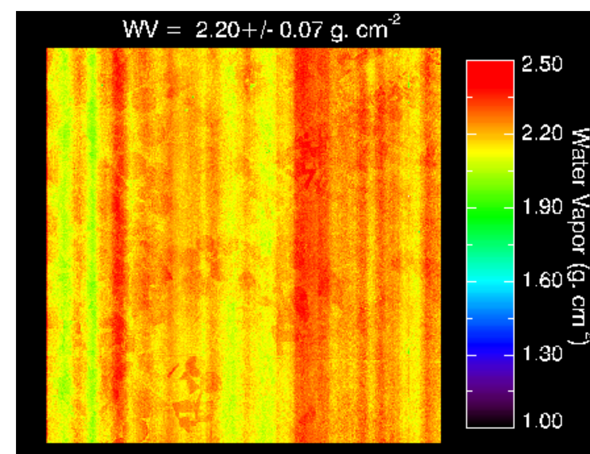
CHRIS_BR_050605_5519_41_



CHRIS_BR_050709_56F4_41_*



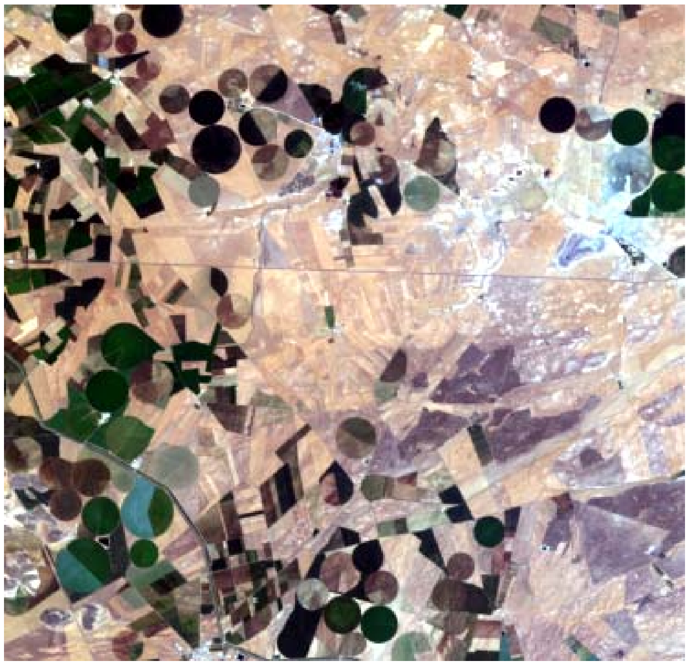


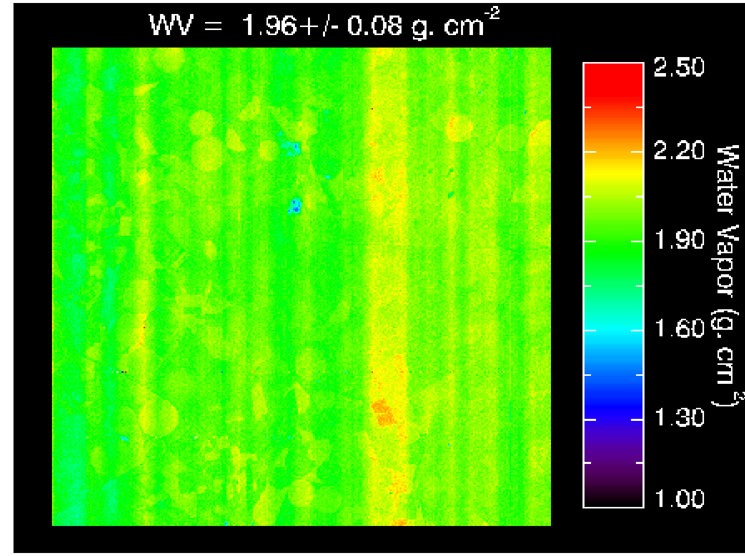


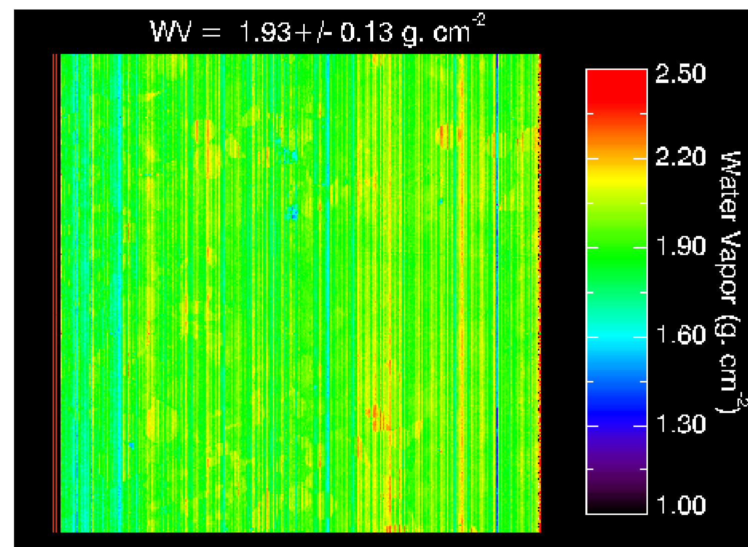
Water vapor maps
SEN2FLEX 2005

Instrumental noise
corrected

CHRIS_BR_050605_5519_41_







Instrumental noise
non-corrected

2.1 Algorithm description

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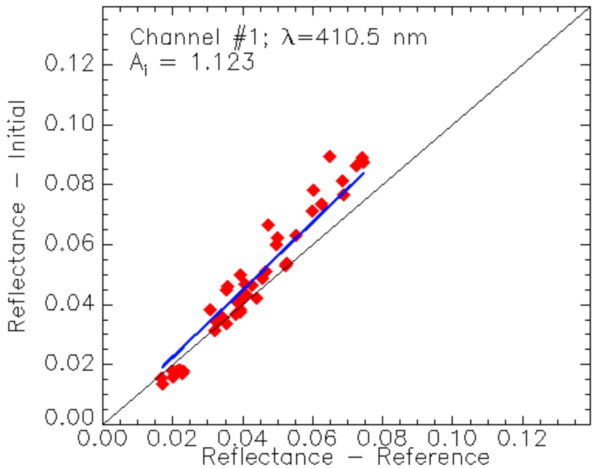
1. Clouds
2. Instrumental noise
3. Spectral calibration
4. Atmospheric conditions
5. **Radiometric calibration**

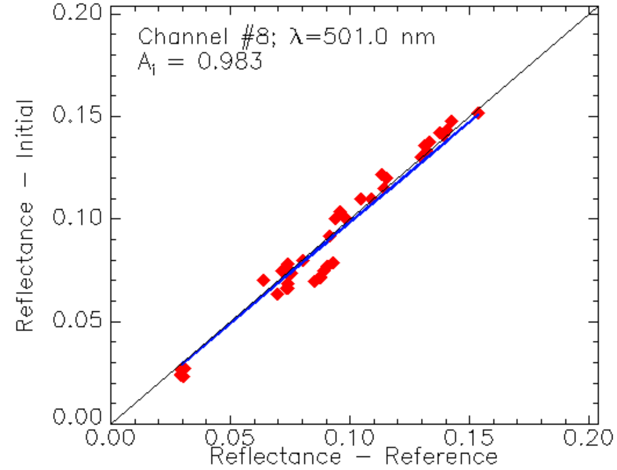
2.1 Algorithm description

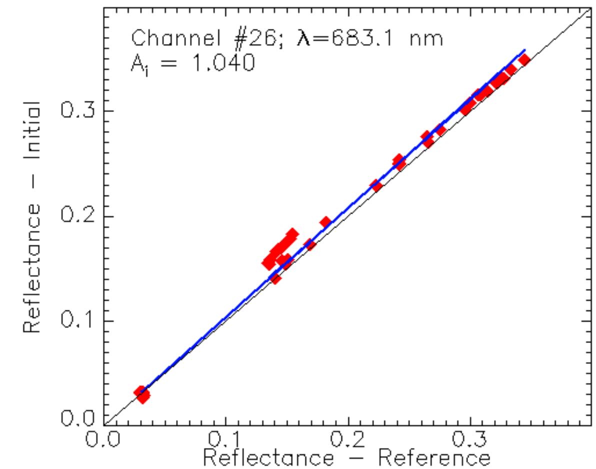
5. Radiometric calibration

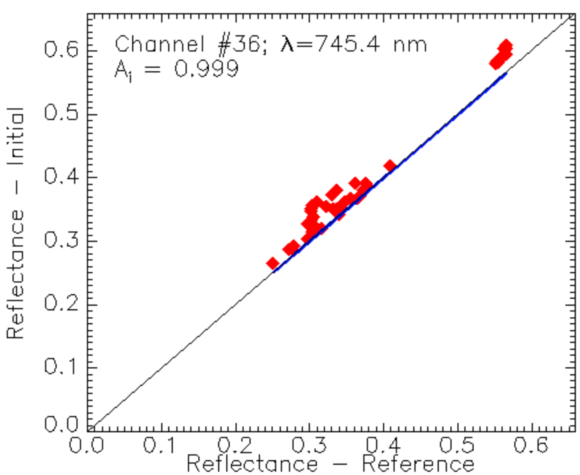
- Applied to Mode-1
- Corrects both errors in radiometric calibration and in RT calculations.
- Problems assumed in gain factors rather than in dark current → $\rho_i^{cal} = A_i \rho_i^{uncal}$
- Up to 50 points per channel fitted by least squares.
- Coefficients calculated from the image with VZA=MZA, an applied to the 5 angles.
- It may modified reflectance values → Selected by the user.

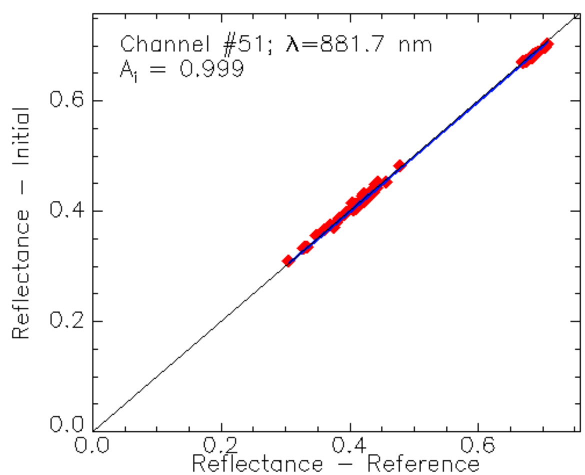
5. Radiometric calibration

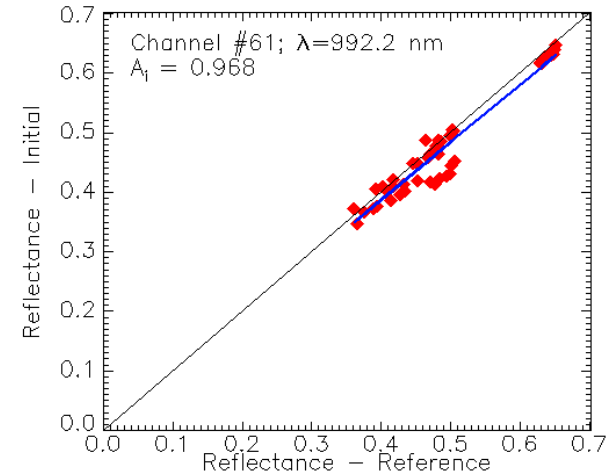






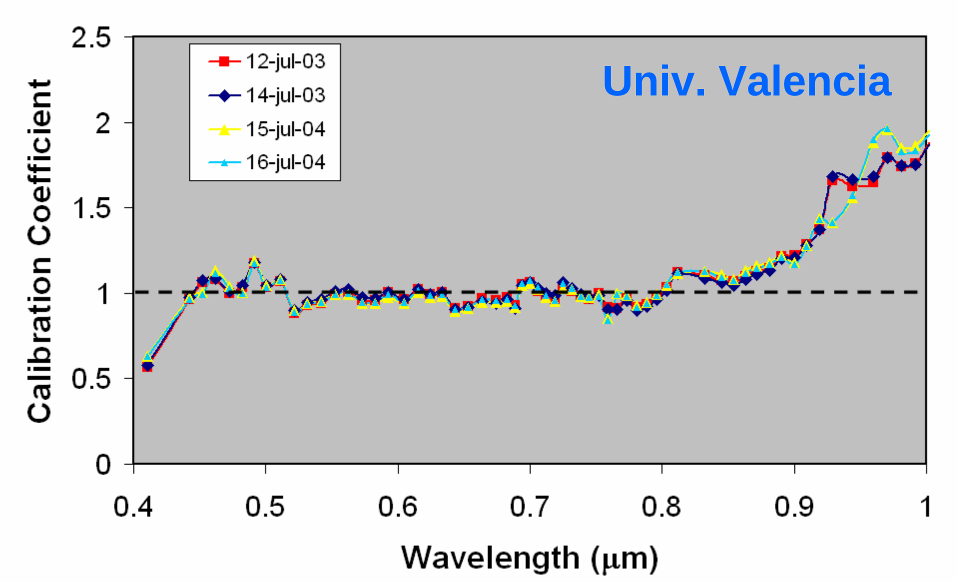


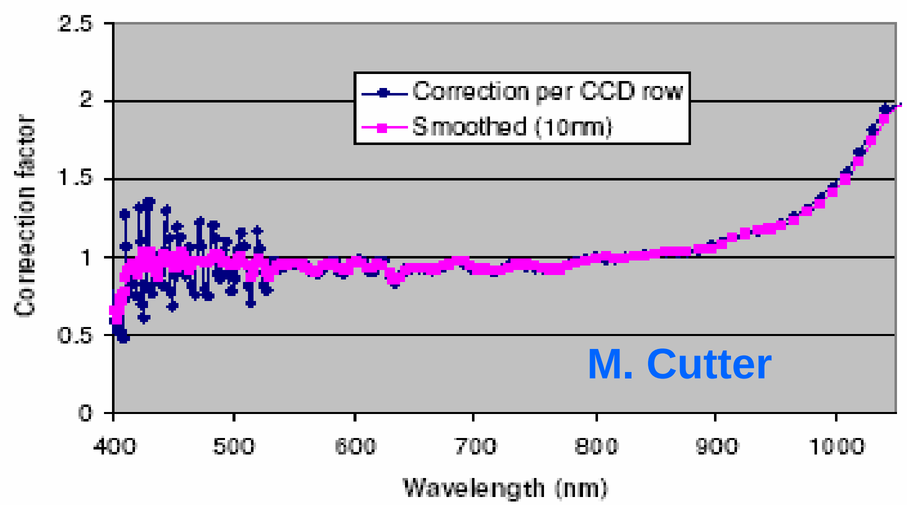


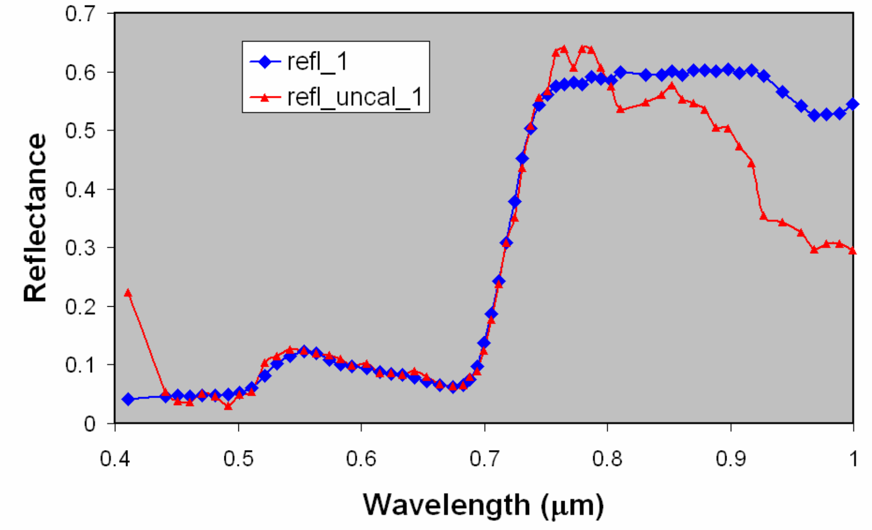


(Processing software 2003/2004)

5. Radiometric calibration

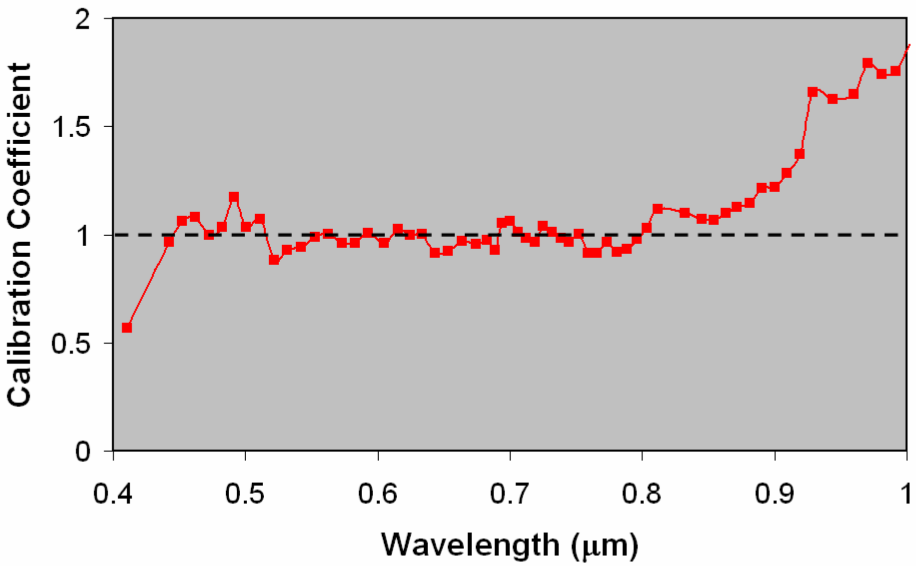




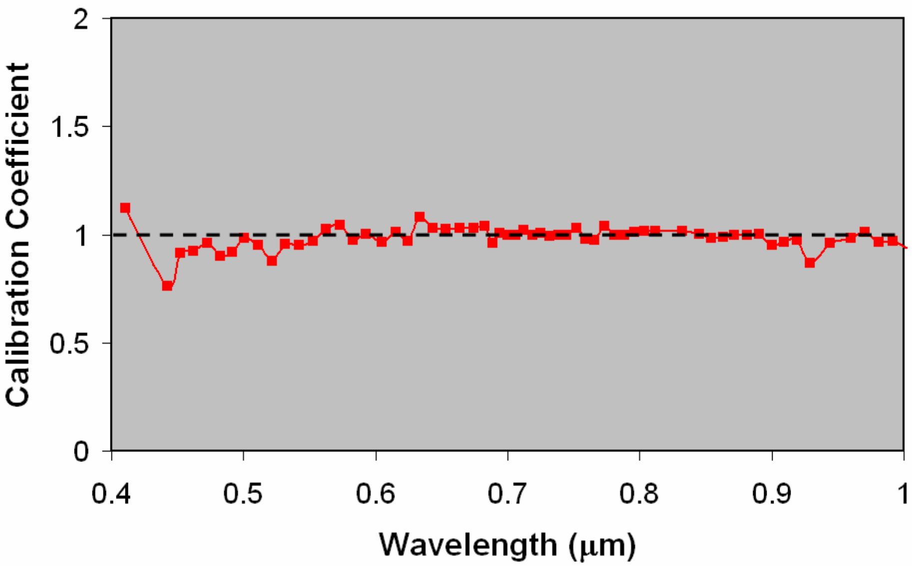


5. Radiometric calibration

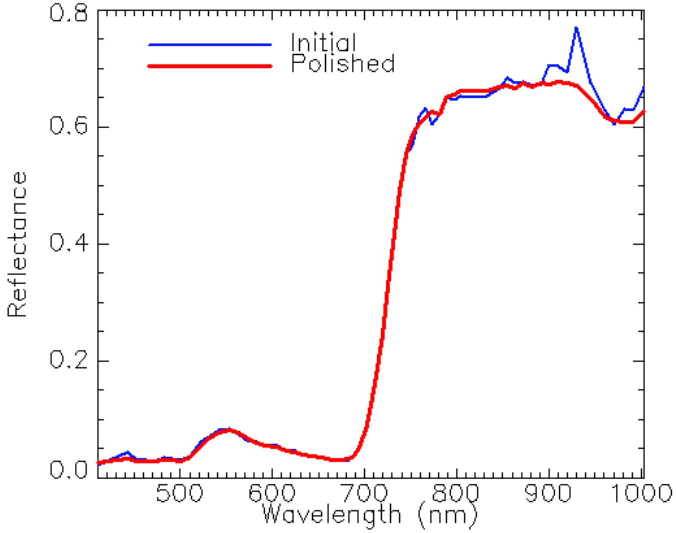
2003 processing software

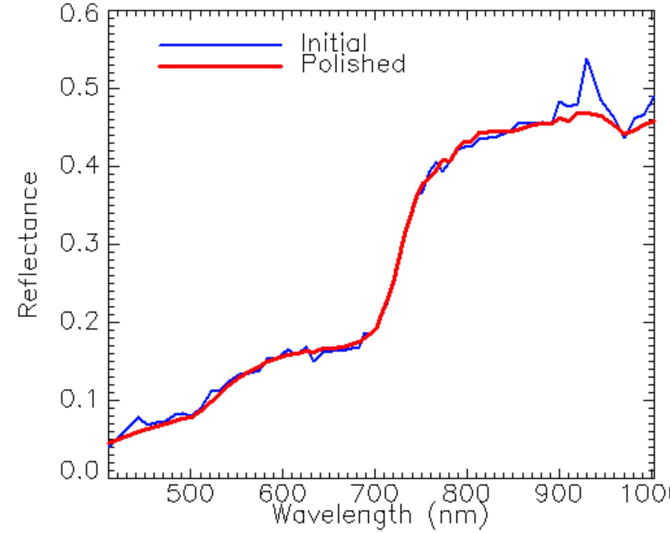


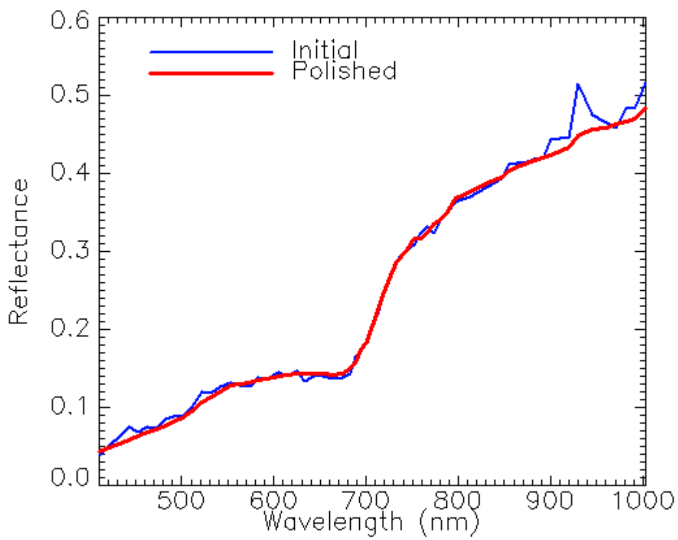
Updated processing software

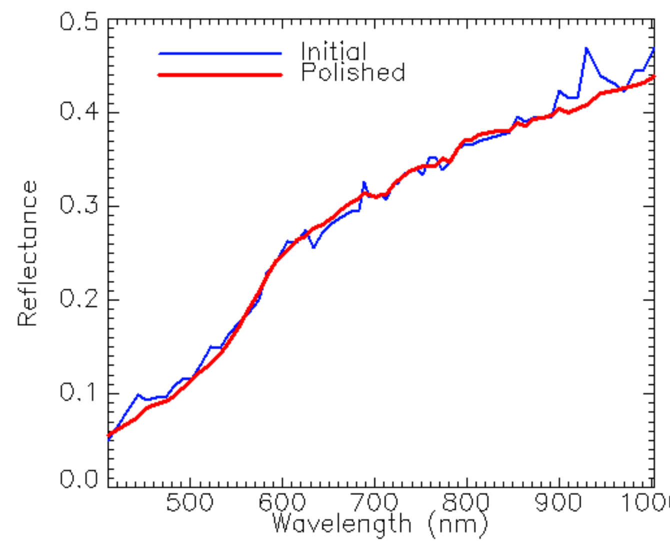


5. Radiometric calibration









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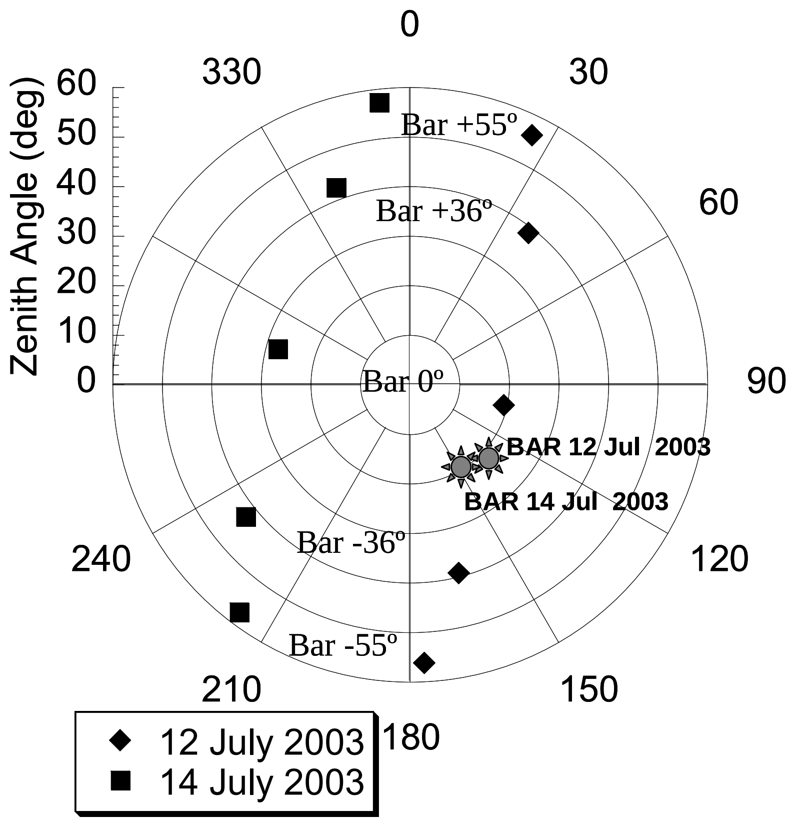
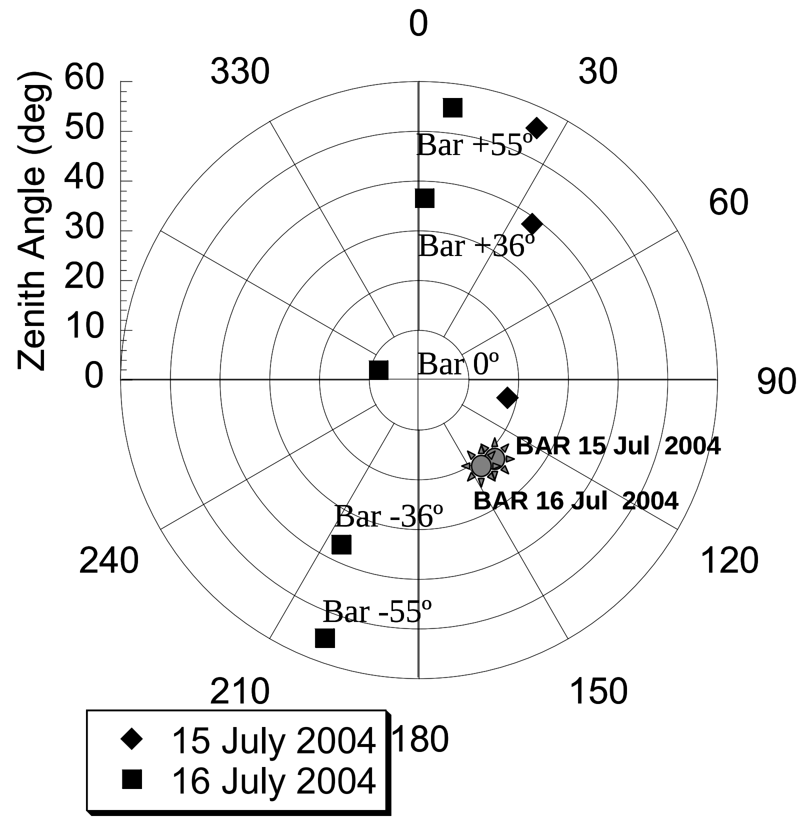
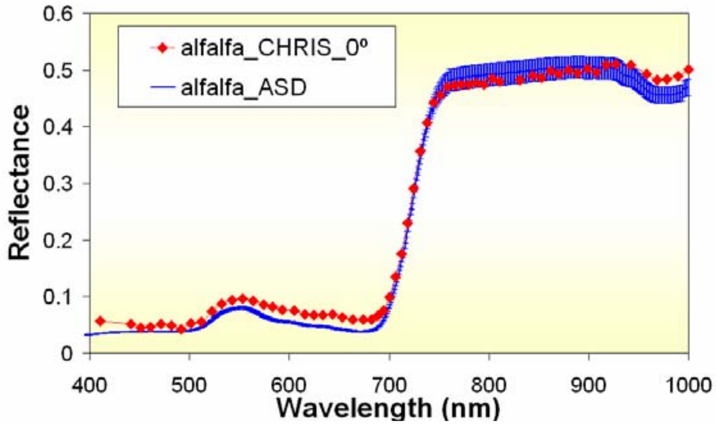
SPARC 2003 & 2004 CHRIS/PROBA Imagery

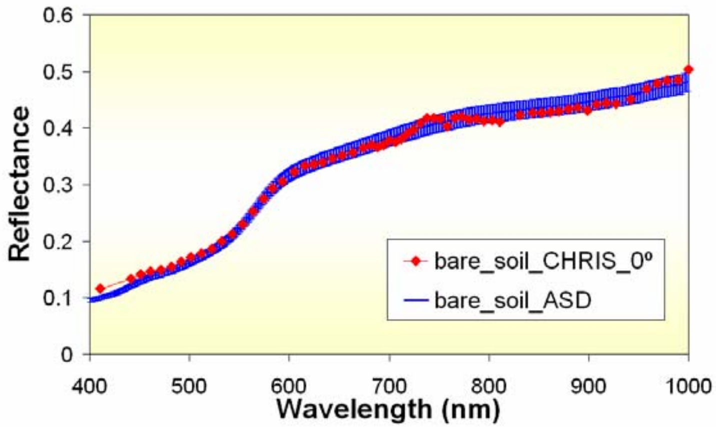
- Mode 1 (62 bands, 34 m/pixel)
- 2003: 2 dates, 12/07/03 & 14/07/03
- 2004: 2 dates, 15/07/04 (fails: FZA=-36º, FZA=-55) & 16/07/04

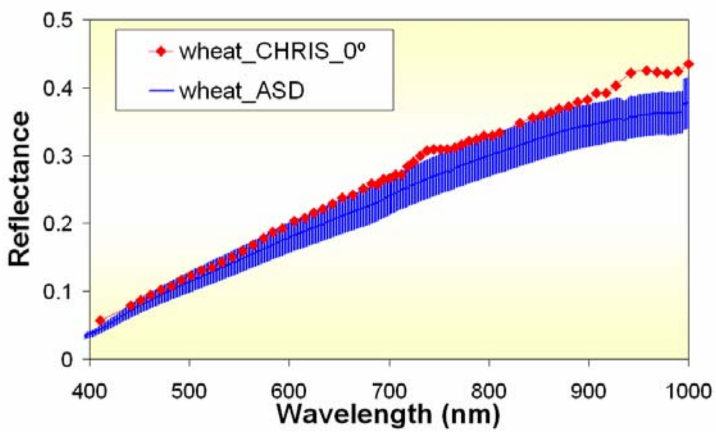




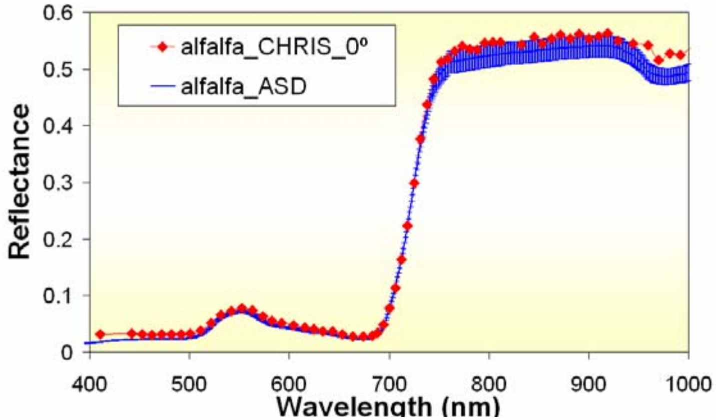
2003

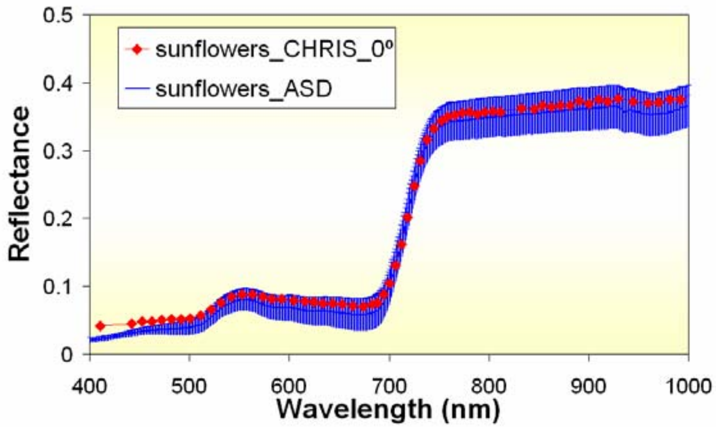

alfalfa_CHRIS_0º
alfalfa_ASD
Reflectance
Wavelength (nm)

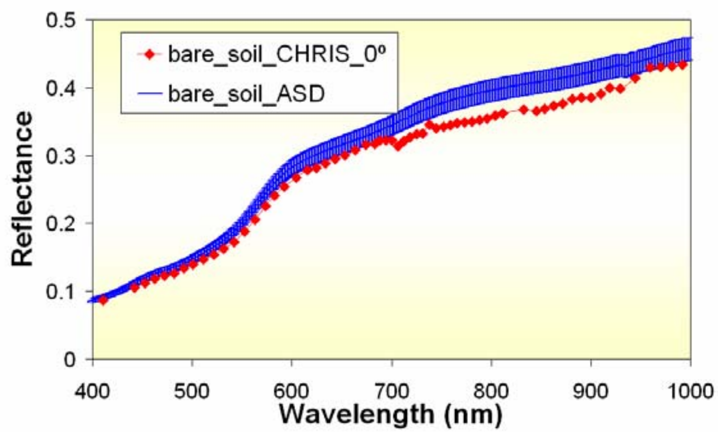

bare_soil_CHRIS_0º
bare_soil_ASD
Reflectance
Wavelength (nm)

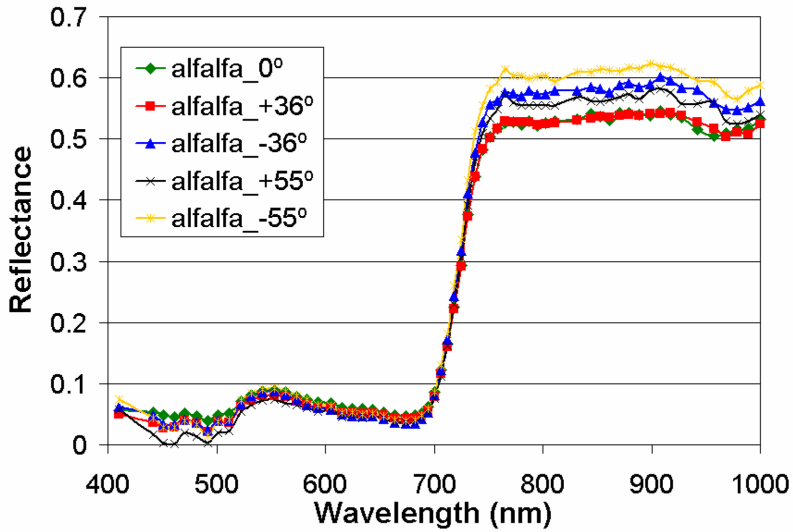

wheat_CHRIS_0º
wheat_ASD
Reflectance
Wavelength (nm)

2004

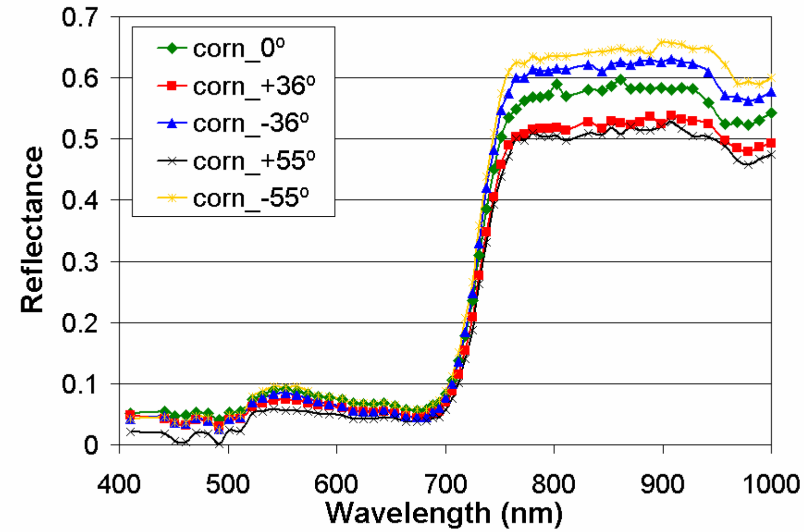

alfalfa_CHRIS_0º
alfalfa_ASD
Reflectance
Wavelength (nm)


sunflowers_CHRIS_0º
sunflowers_ASD
Reflectance
Wavelength (nm)

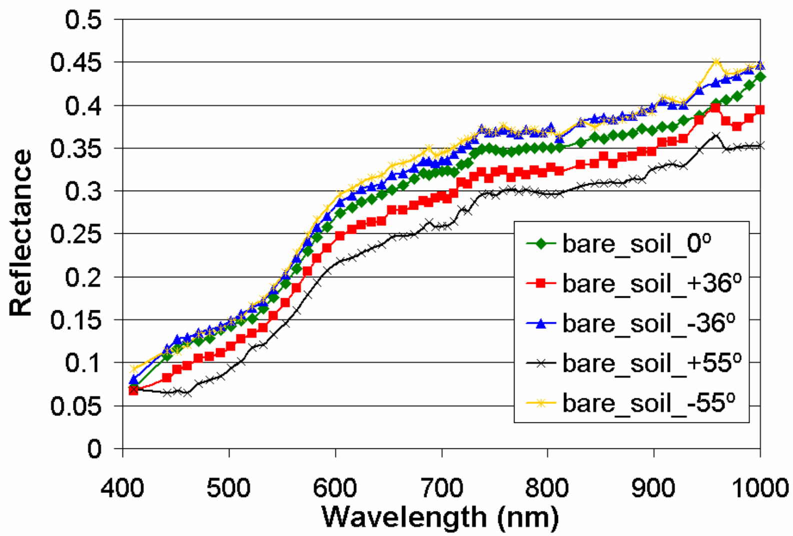

bare_soil_CHRIS_0º
bare_soil_ASD
Reflectance
Wavelength (nm)



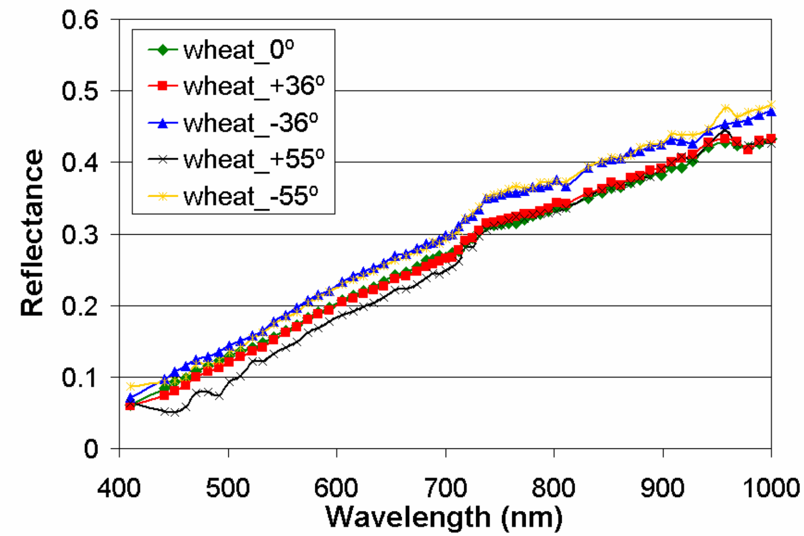
Reflectance
Wavelength (nm)
alfalfa_0º
alfalfa_+36º
alfalfa_-36º
alfalfa_+55º
alfalfa_-55º



Reflectance
Wavelength (nm)
corn_0º
corn_+36º
corn_-36º
corn_+55º
corn_-55º

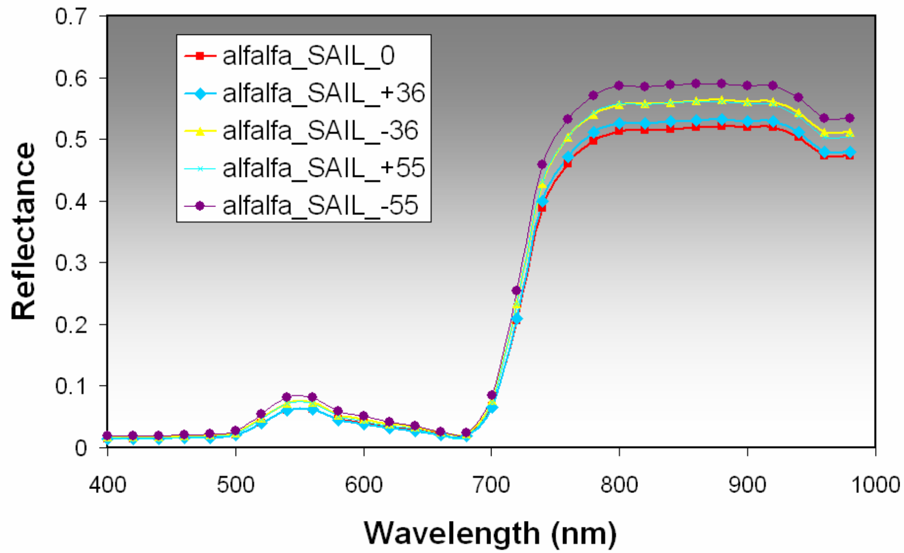


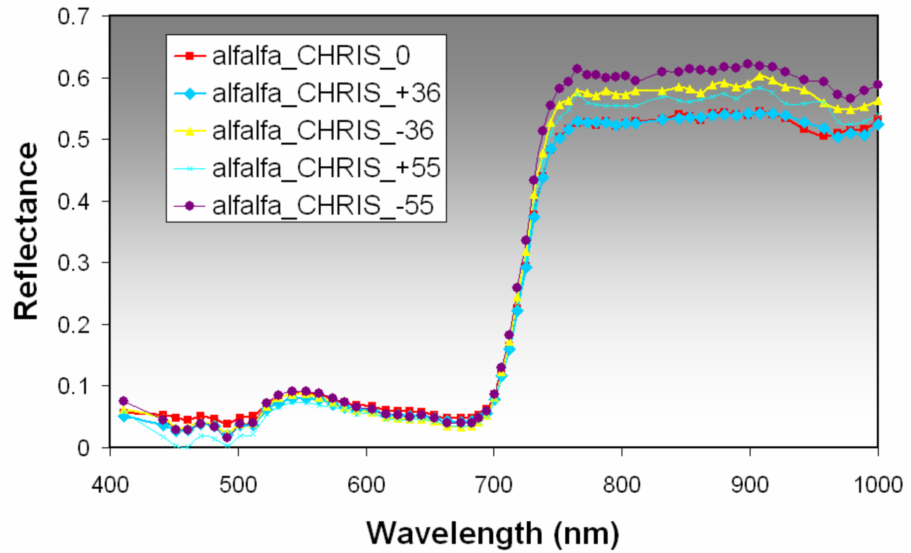
Reflectance
Wavelength (nm)
bare_soil_0º
bare_soil_+36º
bare_soil_-36º
bare_soil_+55º
bare_soil_-55º



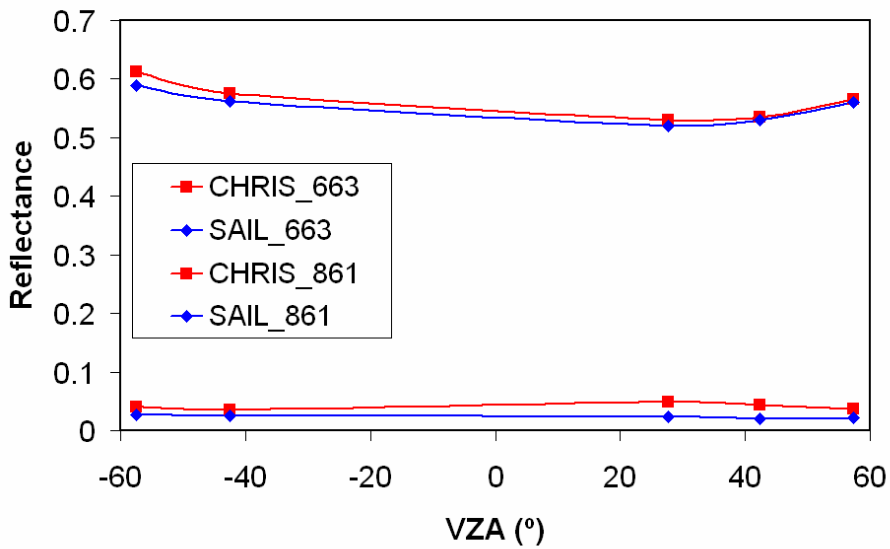
Reflectance
Wavelength (nm)
wheat_0º
wheat_+36º
wheat_-36º
wheat_+55º
wheat_-55º

CHRIS/PROBA – SAIL/PROSPECT (14/07/03)

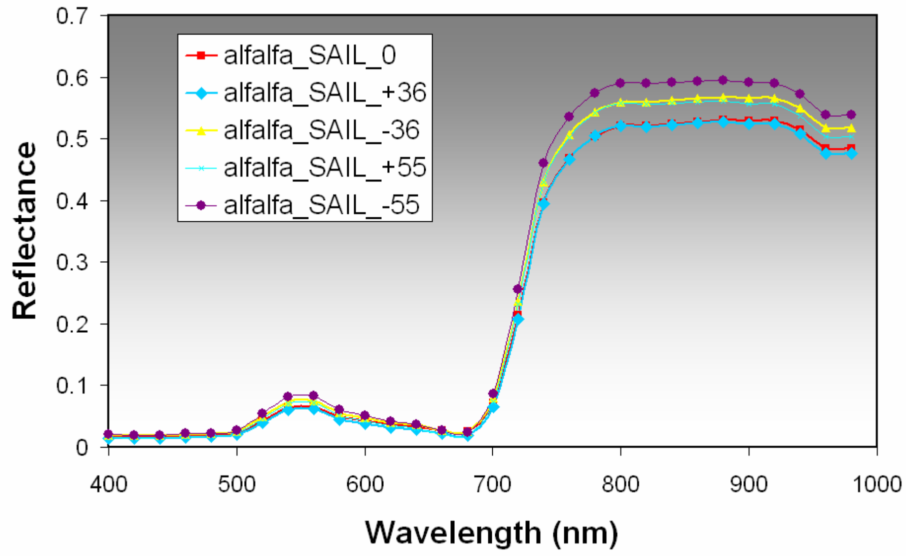


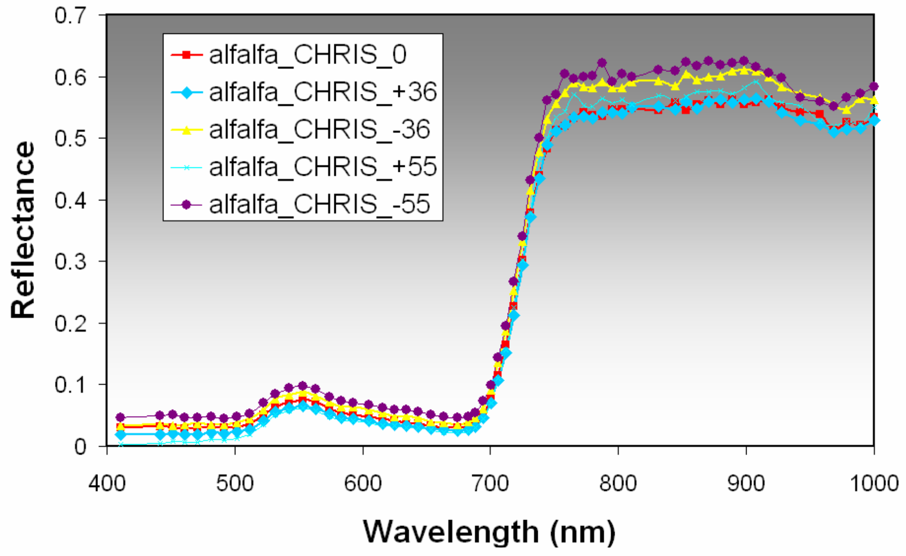


- Cab = 50.17 μg/cm-2
- LAI = 3.73
- Cw = 0.0145 g/cm-2
- Cm = 0.0036 g/cm-2
- N = 1.5

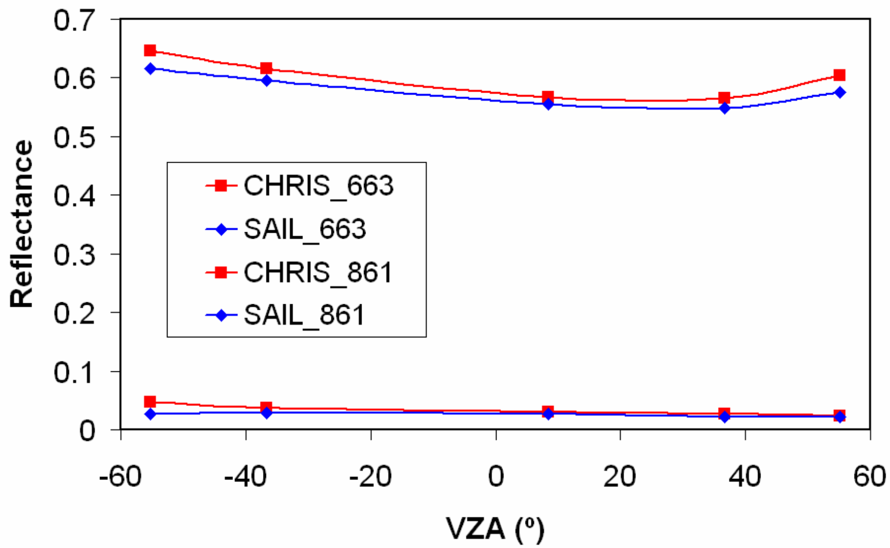


CHRIS/PROBA – SAIL/PROSPECT (16/07/04)





- Cab = 50.17 μg/cm-2
- LAI = 3.73
- Cw = 0.0145 g/cm-2
- Cm = 0.0036 g/cm-2
- N = 1.5

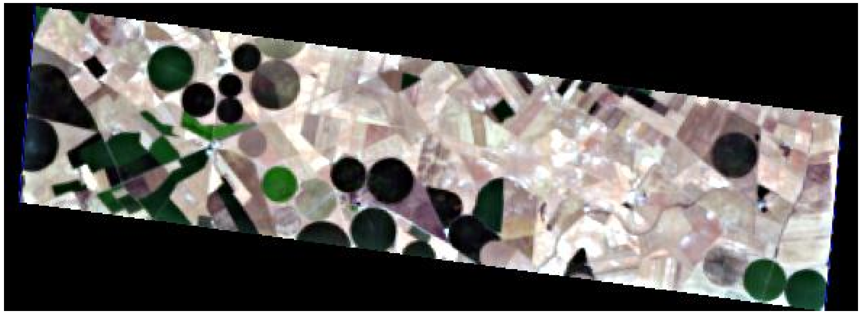


CHRIS/PROBA BARRAX
12/07/03, FZA=0º

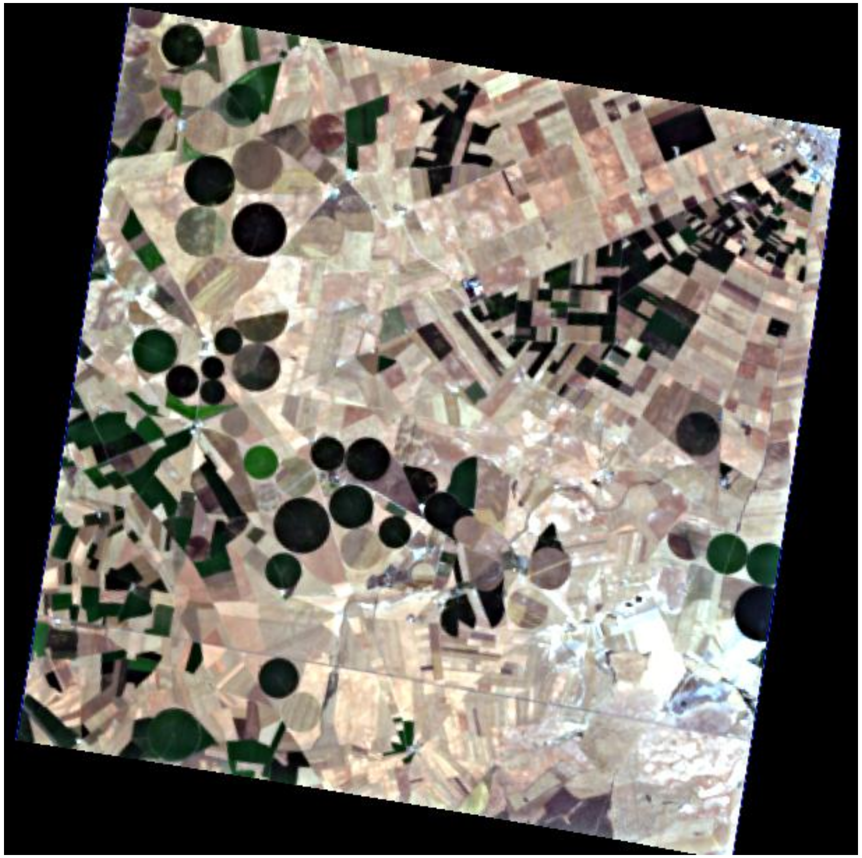
TOA Reflectance image

Surface Reflectance image

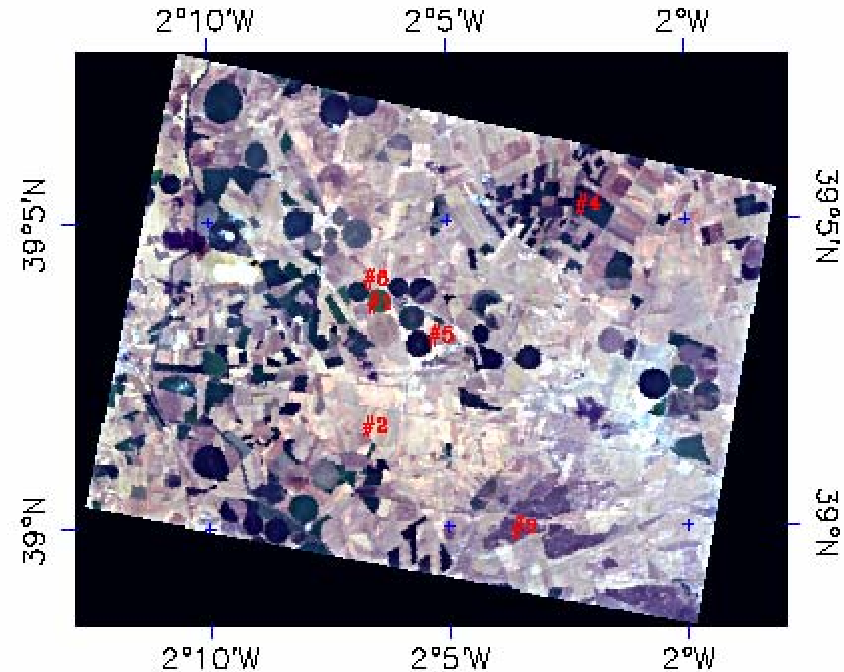
CHRIS/PROBA BARRAX 15/07/04, FZA=0º

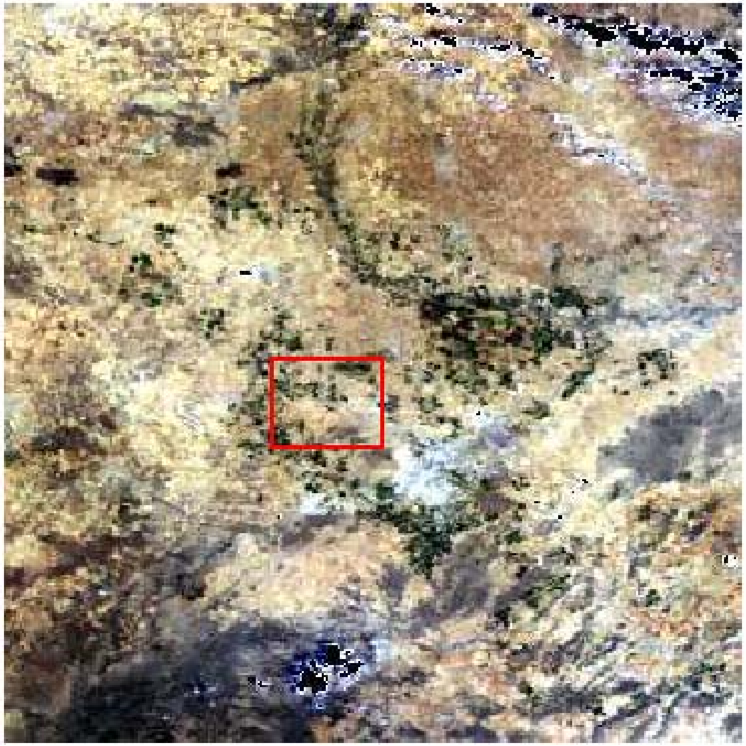


CHRIS/PROBA BARRAX 16/07/04, FZA=0º

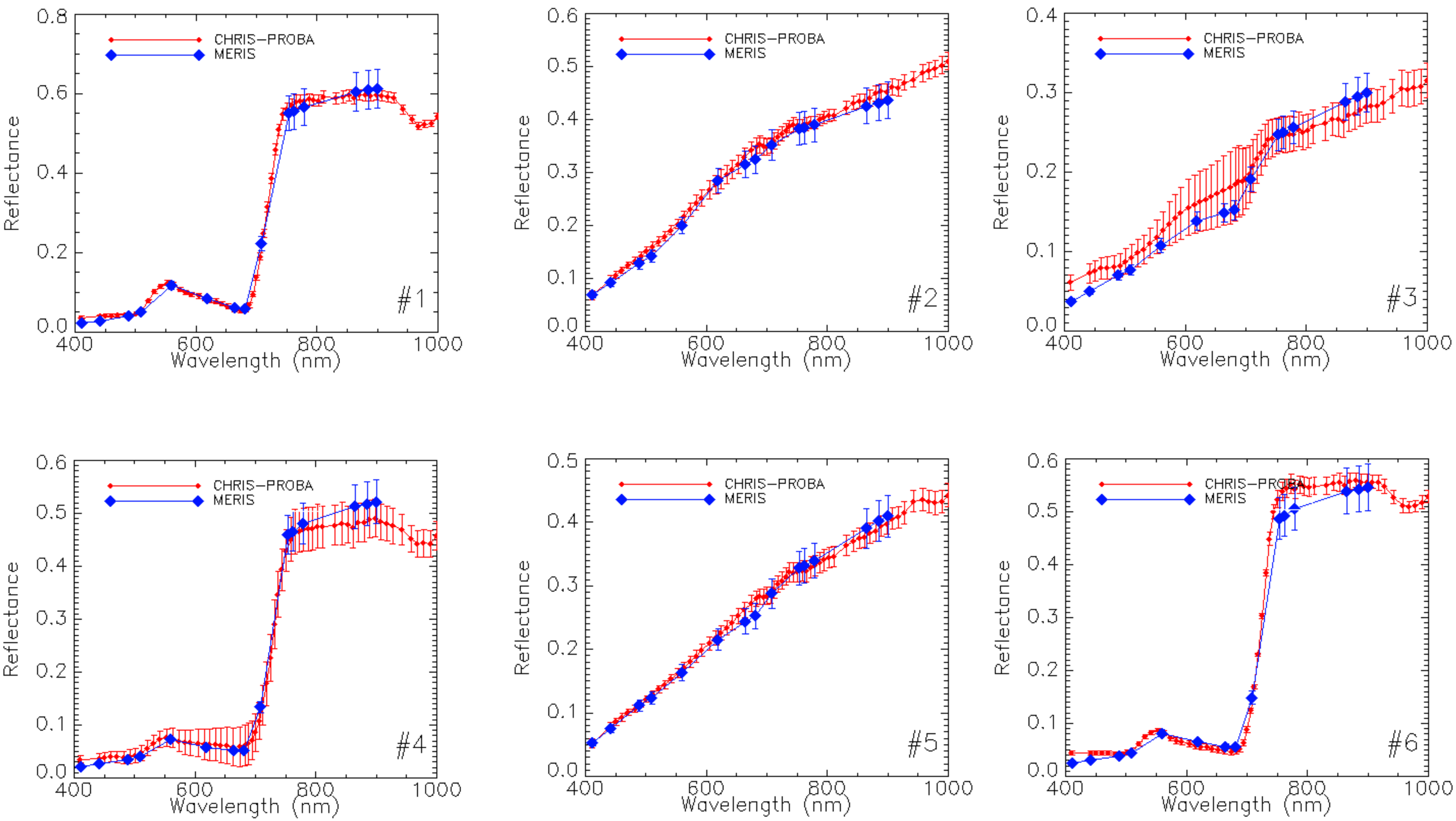


Intercomparison with MERIS data
SCAPE-C vs SCAPE-M





Intercomparison with MERIS data
SCAPE-C vs SCAPE-M



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3. CHRIS/PROBA data over inland waters

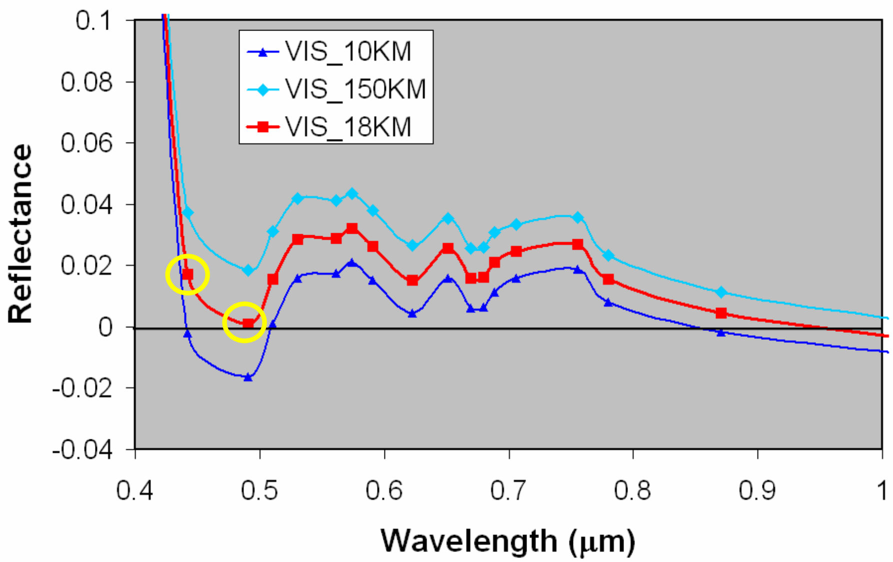
- Radiometric calibration in CHRIS Mode-2 seems to be satisfactory (low S/N in NIR channels). Band #1 (410 nm) useless because of noise. Gaseous absorption skipped.
- Aerosols are the main atmospheric parameter to be estimated.
- Saturation found in bright pixels (ρ>0.25, Cutter p.c.) → Land pixels can not be used for aerosol loading estimations.
- Strategy: estimate aerosol content from bands with a larger contribution of atmosphere in the darkest water pixels.

3. CHRIS/PROBA data over inland waters

- Fundamental basis: AOT calculated from a 'dark' water pixel (FZA=0º), by seeking for the AOT which minimizes

$$\rho^{surf}{}_2(442\ \mathrm{nm})$$

with $\rho^{surf}{}_i > 0$, $i \in [1,14]$

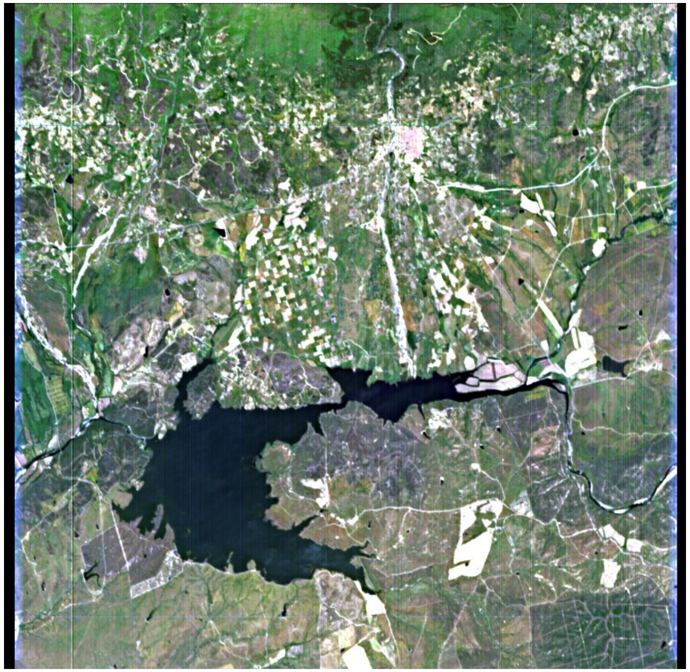


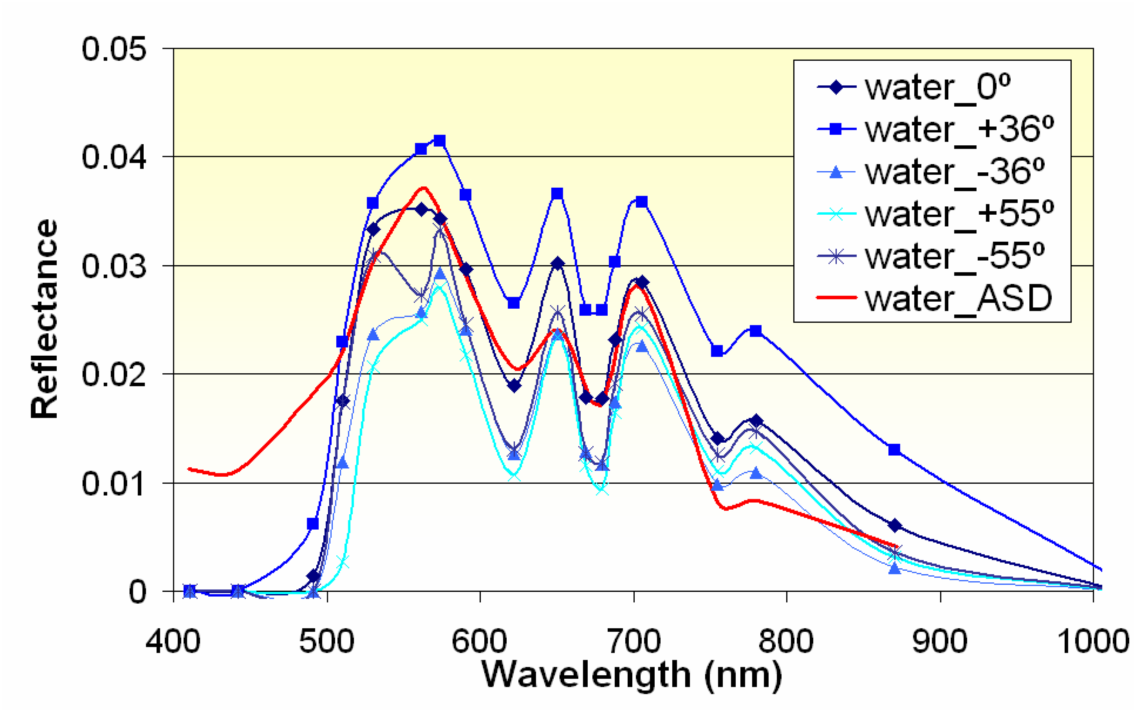
- Atmospheric parameters computed for the 5 angles afterwards.
- Lambertian formulation and adjacency removal complete the procedure.

RESULTS

ROSARITO (20/05/04, FZA=0º)

Mode-2





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4. Summary

- An autonomous method for the **AC of CHRIS/PROBA data over land** (Mode-1) and **inland waters** (Mode-2) has been implemented. Extension to other modes with minor modifications.
- The **sensor spectral & radiometric calibration** are assessed along the AC process of Mode-1 data. Validated against data provided by the operators.
- **SPARC 2003 and 2004 data** used in the validation task:
  - Atmospheric retrievals validated with simultaneous ground-based measurements.
  - Water vapor maps biased by instrumental noise and surface reflectance slope. Errors around 0.1 g·cm^{-2}.
  - Reflectance levels compare well with ASD measurements, MERIS FR data and SAIL/Prospect predictions.

Acknowledgement

- LG acknowledges the support by a PhD fellowship from the Spanish Ministry of Education and Science.
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- The authors also want to thank M. Cutter from Sira Technology Ltd. and to R. Peña, J. A. Domínguez and A. Verdú from CEDEX for the provision with inland waters data.

Coupled Approach for Spectral/Radiometric Calibration and Surface Reflectance Retrieval from CHRIS/PROBA Data

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4th ESA CHRIS/PROBA Workshop, ESA/ESRIN, September 19-21th 2006