Atmospheric Correction of CHRIS/PROBA data acquired in the SPARC campaign

L. Guanter, L. Alonso and J. F. Moreno
Faculty of Physics, University of Valencia
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   - Atmosphere decoupling technique
   - Adjacency effects
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1. Introduction

- A major problem in atmospheric correction is the accurate knowledge of the atmospheric state (principally gases concentrations and aerosols content and type). Atmosphere radiative effects must be separated from surface ones.

- Combinations of several bands and/or directions make the separation of surface and atmospheric effects possible.

- We have designed an atmospheric correction algorithm based on the retrieval of atmospheric parameters from hyperspectral data.
1. Introduction

- The algorithm has been applied to the SPARC satellite data atmospheric correction.

- CHRIS/PROBA (12/07/03) and MERIS (14/07/03) images are already corrected.

- Campaign ground measurements used only for the validation of intermediate (water vapor and aerosols) and final products (surface reflectance).
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2. Algorithm description

Atmospheric parameters retrieval

First step for atmospheric correction: retrieval of the main atmospheric information.

- **Gases**
  - Ozone column content → Satellite databases
  - Vertical profiles → US62 standard model as default

- **Aerosols and water vapor**
  - Water vapor column content
  - Aerosols total content
  - Aerosols type → Multiparameter inversion of TOA radiances

Resultant values are used to calculate gases and aerosols atmospheric reflectances and transmittances with 6S radiative transfer code.
2. Algorithm description

Atmospheric parameters retrieval

Aerosols and Water Vapor retrieval

- Atmosphere is considered invariant inside a 30x30km window, while surface reflectance varies from pixel to pixel.

- Water vapor, aerosols information and surface vegetation/soil proportions are retrieved simultaneously from 5 pixels of the satellite image inside this window.

- The retrieval procedure consist of a multiparameter inversion of the TOA spectral radiances from selected combinations of bands.

- With the purpose of improving the numerical stability in the inversion process, 5 pixels in this window are chosen, ranging from high vegetation proportion to high soil proportion when possible.
2. Algorithm description

Data to be obtained from the inversion are

- Water Vapor Column Content.
- Aerosol Optical Thickness (550 nm).
- % of aerosol species Dust Like, Water Soluble, Oceanic, Soot.
- Proportions of vegetation and soil in the 5 pixels.

Merit Function:

\[
\delta^2 = \sum_{pix=1}^{5} \sum_{\lambda_i} \frac{1}{\lambda_i^2} \left[ \rho_{TOA}(pix, \lambda_i) - \rho_{SIM}(pix, \lambda_i) \right]^2
\]

Chi-square function is weighted by \(1/\lambda^2\) to drive the inversion towards smaller wavelengths, where aerosol effects are bigger.

Wavelengths are selected depending on the band configuration of the sensor.
2. Algorithm description

Atmospheric parameters retrieval

Band selection CHRIS

- Bands with weaker gaseous absorption are selected.
- Extreme bands in CHRIS are not considered because of calibration problems. Oxygen (760 nm) and the center of the water vapor band in 940 nm are also discarded.
2. Algorithm description

Atmospheric parameters retrieval

TOA reflectances construction for the inversion

- Spectral bands are simulated by means of the corresponding function to each sensor.
- VZA, VAA, latitude, longitude, acquisition time, ozone column and surface average height are inputs.
- Water vapor specified by the integrated column (g·cm⁻²).
- Aerosols are characterized by the optical thickness in 550nm and the percentage of 4 standard types: Dust Like, Water Soluble, Oceanic and Soot, variables of the inversion.
2. Algorithm description

Atmospheric parameters retrieval

- Surface reflectance is given by the linear combination of 2 endmembers of typical vegetation (alfalfa) and soil spectra:

\[
\rho_s = C_v \rho_{veg} + C_s \rho_{soil}
\]

- \( C_v, C_s \in [0, 1.5] \), to consider natural surfaces brighter than the endmembers. The 10 values for these coefficients are also variables of the inversion procedure.
2. Algorithm description

Atmospheric parameters retrieval

- 15 free parameters to be obtained by the inversion:
  - 1 for water vapor column content.
  - 4 for specifying the optical thickness (550 nm) and the proportions of the basic aerosol types.
  - 10 for the proportions $C_v$ and $C_s$ of the 5 pixels.

- Powell’s Minimization Method has been chosen for the inversion, because of its speed of convergence and its discrimination of local minima.

- Initialization of Powell algorithm
  - Water vapor: 2.0 g·cm$^{-2}$
  - AOT: 0.235, corresponding to 23 km of visibility.
  - Aerosol species:
    - Dust Like: 15%
    - Water Soluble: 40%
    - Oceanic: 40%
    - Soot: 5%

Rural + Maritime model
2. Algorithm description

- Soil and vegetation proportions: A correlation between $C_v$, $C_s$ and NDVI is found from several simulations.

- Quality of the fits shows that initialization values of $C_v$ and $C_s$ are very close to those of the final solution.
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**Lambertian surface assumption**

- 6S-like signal construction, assuming Lambertian reflectance for the target

\[
\rho_{TOA}(\mu_s, \mu_v, \phi) = t_g \left[ \rho_0 + \frac{(e^{-\tau/\mu_s} + t_d(\mu_s))(e^{-\tau/\mu_v} + t_d(\mu_v))\rho_s}{1 - S \rho_s} \right]
\]

- Analytically invertible to retrieve \( \rho_s \).

\[
\rho_s(\mu_s, \mu_v, \phi) = \frac{\rho_{TOA}}{t_g} - \rho_0
\]

\[
= \frac{(e^{-\tau/\mu_s} + t_d(\mu_s))(e^{-\tau/\mu_v} + t_d(\mu_v)) + \frac{\rho_{TOA}}{t_g} - \rho_0}{(e^{-\tau/\mu_s} + t_d(\mu_s))(e^{-\tau/\mu_v} + t_d(\mu_v)) + \frac{\rho_{TOA}}{t_g} - \rho_0} \]

- Atmospheric reflectances and transmittances are provided by the 6S code, once gases concentrations and aerosol content and type are known.
BRDF Retrieval

Simultaneous Multiangular data

\[
\rho_{\text{TOA}}(\mu_s, \mu_v, \phi) = t_g \left[ \rho_0 + e^{-\tau/\mu_s} e^{-\tau/\mu_v} \rho_s(\mu_s, \mu_v, \phi) + e^{-\tau/\mu_v} t_d(\mu_s) \tilde{\rho} + e^{-\tau/\mu_s} t_d(\mu_v) \tilde{\rho}' + t_d(\mu_s) t_d(\mu_v) \tilde{\rho} + \frac{(e^{-\tau/\mu_s} + t_d(\mu_s))(e^{-\tau/\mu_v} + t_d(\mu_v)) S(\tilde{\rho})^2}{1 - S \tilde{\rho}} \right]
\]

- Decoupling technique improving the Lambertian surface approach.
- Directional properties are taken into account.
- Resultant coupling terms: make the equation no invertible.

\[
\tilde{\rho} = \frac{\int_0^{2\pi} \int_0^1 \mu L_1(\mu_s, \mu, \phi') \rho_s(\mu_s, \mu_v, \phi' - \phi) d\mu d\phi'}{\int_0^{2\pi} \int_0^1 \mu L_1(\mu_s, \mu, \phi') d\mu d\phi'}
\]

\[
\tilde{\rho}'(\mu_s, \mu_v, \phi) = \tilde{\rho}(\mu_v, \mu_s, \phi)
\]

\[
\tilde{\rho} = \int_0^{2\pi} \int_0^1 \rho_s(\mu, \mu', \phi) \mu \mu' d\mu' d\mu d\phi
\]

2nd ESA CHRIS/Proba Workshop, April 28-30th, Frascati
Simultaneous Multiangular data

\[
\rho_{TOA}(\mu_s, \mu_v, \phi) = \tau_g \left[ \rho_0 + e^{-\tau/\mu_s} e^{-\tau/\mu_v} \rho_s(\mu_s, \mu_v, \phi) \\
+ e^{-\tau/\mu_v} t_d(\mu_s) \tilde{\rho} + e^{-\tau/\mu_s} t_d(\mu_v) \tilde{\rho}' \\
+ t_d(\mu_s) t_d(\mu_v) \tilde{\rho} + \frac{(e^{-\tau/\mu_s} + t_d(\mu_s))(e^{-\tau/\mu_v} + t_d(\mu_v)) S(\tilde{\rho})^2}{1 - S\tilde{\rho}} \right]
\]

- Decoupling technique improving the Lambertian surface approach.
- Directional properties are taken into account.
- Resultant coupling terms: make the equation no invertible.
Simultaneous Multiangular data

Problem: To derive $\rho_s$ the coupling terms are needed. These, in turn, are calculated from $\rho_s$.

Previous information on $\rho_s$ is needed to do an initial approximated calculation of the coupling terms.

Solution: Initial correction with the Lambertian surface approach.

Iterative process (Vermote et al.): Retrieved surface is fitted to the RPV model $\rightarrow$ calculation of coupling terms $\rightarrow$ newer values of $\rho_s$ retrieved.

Directional-directional reflectance (BRDF) and spectral albedo obtained as a result.
2. Algorithm description

Atmosphere decoupling technique

Lambertian vs Directional Reflectance

- Lambertian assumption applied to complete CHRIS/PROBA images so far.

- BRDF effects considered only for some discrete pixels because:
  - There is not a total overlapping for the 5 images, so an initial test of the number of angles needed to perform an adequate BRDF correction should be done for areas not viewed from all of the angles.
  - Current geometric correction has an error of around 100 m in the surface:
    - difficult to assert the same pixels are viewed from the 5 angles.
    - pixel dimension varies with the VZA.
  - Fit to the RPV model is computationally very expensive on a pixel by pixel basis (#Fits ~ $10^6$ pixels x nº iter).
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Adjacent 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.

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

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

\[
\bar{\rho} = \frac{1}{N^2} \sum_{i,j=1}^{N} \rho_{i,j}^{\text{blur}}, \quad N = \begin{cases} 30 & \text{CHRIS} \\ 3 & \text{MERIS FR} \end{cases}
\]

The strength of the adjacency effect is given by the ratio of diffuse to direct ground-to-sensor transmittance.
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MODTRAN4 CHRIS Simulations
For a first validation of the algorithm, 10 TOA high resolution spectra have been simulated with MODTRAN4:

- Midlatitude summer standard atmosphere
- Aerosol visual range of 23 km, rural model
- Surface with variable proportions of vegetation and soil, ranging from 100% to 0%.

Those spectra have been filtered to CHRIS band configuration (MODE 1, 62 bands).

Different sets of 5 pixels are chosen, with dominant vegetation contribution, soil contribution or equal proportions of both.

Validation is focused on testing surface reflectance spectra retrieval in the case of one viewing direction satellites.
CHRIS simulated TOA Reflectances

MODTRAN4
CHRIS Filter

Cv=100%, Cs=0%

Cv=67%, Cs=33%

Cv=33%, Cs=67%

Cv=0%, Cs=100%
CHRIS Simulations Fits
Aerosol retrievals:

- Visibility: 8.5km (AOT(550nm)=0.54)
- Types:
  - 20% Dust Like
  - 40% Water Soluble
  - 40% Oceanic
  - 0% Soot

Veg/Soil coefficients (\(C_v, C_s\)):

<table>
<thead>
<tr>
<th>Spt</th>
<th>(C_v)</th>
<th>(C_s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spt1</td>
<td>1.002</td>
<td>1.70E-08</td>
</tr>
<tr>
<td>Spt2</td>
<td>0.758</td>
<td>0.249</td>
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<tr>
<td>Spt3</td>
<td>0.5</td>
<td>0.512</td>
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<tr>
<td>Spt4</td>
<td>0.243</td>
<td>0.775</td>
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<tr>
<td>Spt5</td>
<td>1.9E-06</td>
<td>1.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Input values</th>
</tr>
</thead>
</table>

Water vapor retrieval (gm·cm\(^{-2}\)):

<table>
<thead>
<tr>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.93</td>
</tr>
</tbody>
</table>

Input: 2.05
CHRIS Simulations
Corrected Spectra
CHRIS Simulations
Corrected Spectra

Systematic fluctuations
CHRIS Simulations
Recalibration Coefficients

\[ C_v \rho_{\text{veg}} + C_s \rho_{\text{soil}} = A \cdot \rho_s^{retr} \]
CHRIS Simulations
Recalibration Coefficients
CHRIS Simulations
Corrected Spectra Recalibration
CHRIS/PROBA data (MODE 1)

Image 12/07/2003, FZA=0°
CHRIS data Fits
CHRIS data Fits

Calibration problems?
Aerosol retrieval validation

Comparison between the global and direct irradiance given by the RT model and the LICOR ground measurements

12/07/03
VIS = 26.9km
%DL= 14.4
%WS=39.4
%OC=40.0
%SO= 6.2

14/07/03
VIS = 17.8km
%DL= 16.2
%WS=39.8
%OC=40.0
%SO= 4.0
Water vapor retrieval validation

- Comparison between the column content retrieved by the algorithm and the radiosoundings integrated amount

<table>
<thead>
<tr>
<th>Date</th>
<th>Algorithm (g/cm²)</th>
<th>Radiosounding (g/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/07/03</td>
<td>1.62</td>
<td>1.46</td>
</tr>
<tr>
<td>14/07/03</td>
<td>1.82</td>
<td>1.61</td>
</tr>
</tbody>
</table>
CHRIS data Corrected Spectra

Systematic fluctuations
CHRIS data
Recalibration Coefficients
CHRIS data
Recalibration Coefficients

\[ y = 33.534x^3 - 66.944x^2 + 44.132x - 8.6195 \]

\[ R^2 = 0.9007 \]
CHRIS data Recalibrated Spectra
CHRIS Recalibrated Spectra
CHRIS TOA Radiance Recalibration

Calibration problems

2nd ESA CHRIS/Proba Workshop, April 28-30th, Frascati
CHRIS Angular Patterns
CHRIS_3598 (12/07/03, FZA=0°)

TOA Reflectance image

Surface Reflectance image
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MERIS sensor data

Image FR - 14/07/2003
MERIS Barrax 14/07/03
MERIS data Fits
MERIS data Corrected Spectra
MERIS Barrax 14/07/03

TOA Reflectance image  
Surface Reflectance image
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A method has been developed to perform the atmospheric correction of hyperspectral satellite data taken over land.

Atmospheric parameters needed for the correction are extracted from the image.

An initial validation has been performed using MODTRAN4 simulations of CHRIS TOA radiances.
4. Conclusions

The algorithm has been used for the atmospheric correction of the SPARC satellite data:

• Retrieved atmospheric parameters in good agreement with irradiance measurements and radiosoundings.

• A recalibration of the surface reflectance is needed for CHRIS/PROBA data: coefficients obtained as an algorithm output.

Further validation with other campaign measurements (aerosols and water vapor profiles, surface spectra...) still needed.
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- Pixel by pixel water vapor retrieval (?)
- Consistency tests by means of spatial resolution scaling analysis.
- Improvements in the adjacency effect treatment (spatial frequencies contribution analysis?).
- Including multiangular information in the discrimination of aerosol types when simultaneous multiangular data available.
- Checking the robustness of the recalibration coefficients for CHRIS/PROBA, in temporal and target type terms.