Application of the SCAPE-M atmospheric correction algorithm to the processing of MERIS data over continental water bodies

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Contents

I. Introduction

II. Algorithm Theoretical Background

III. Overall Validation

IV. Results from Continental Water Bodies

V. Summary and Conclusions
Contents

I. Introduction

II. Algorithm Theoretical Background

III. Overall Validation

IV. Results from Continental Water Bodies

V. Summary and Conclusions
I. Introduction

**SCAPE-M** (Self-Contained Atmospheric Parameters Estimation from MERIS data) code for atmospheric correction of MERIS developed.

Atmospheric Processor: aerosol optical thickness (AOT), columnar water vapor (CWV) and reflectance maps automatically generated from MERIS L1b data.

Designed to work over land, but application to “close-to-land” water targets also enabled.

Validation over land → Comparison with ground-based data and other satellite products, more than 200 images processed.
I. Introduction

Solid validation over continental water bodies was still remaining.

2007-2008:

- SCAPE-M applied to MERIS L1b FR data over inland waters in the Iberian Peninsula and Finland.
- Up to 18 validation points (11 reservoirs and lakes) with simultaneous ground-based atmospheric and/or water leaving reflectance measurements available.
I. Introduction

II. Algorithm Theoretical Background

III. Overall Validation

IV. Results from Continental Water Bodies

V. Summary and Conclusions
II. Algorithm Theoretical Background

Radiative transfer calculations

- Atmospheric optical parameters derived from a LUT computed from MODTRAN4.
- Elevation effects considered on a per-pixel basis.

DEM  \[ L_0 \]  \[ E_{\text{dir}} \cdot \mu_s \]  \[ E_{\text{dif}} \]
II. Algorithm Theoretical Background

Cloud screening based on static thresholds over TOA reflectance and spectral slope.

- 2 sets of thresholds:
  - “Restrictive” set: detects pixels with minimum probability of clouds → AOT retrieval
  - “Relaxed” set: detects pixels with a high probability of clouds → CWV and reflectance retrieval
II. Algorithm Theoretical Background

Inland Water masking

- Small lakes missed in the MERIS L1 Water Mask.
- Empirical mask:
  - $\rho_{\text{TOA}}(865\text{nm})<0.08$
  - Less than 10 km to the coast
  - Less than 400 km$^2$

$\rightarrow$ Inland waters defined by
Topographic effects

\[
L_{\text{TOA}} = L_0 + \frac{1}{\pi} \frac{\rho_s (E_{\text{dir}} \mu_{il} + E_{\text{dif}} T)}{1 - S \rho_s}
\]

\[\mu_{il} = n \cdot S \rightarrow \text{Cosine correction}\]

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

\[\rightarrow \text{Hay’s model}\]
II. Algorithm Theoretical Background

AOT retrieval

- Aerosol retrieval integrated on 30x30 km² cells.
- Aerosol loading characterized by AOT at 550 nm.
- Aerosol type fixed to rural model.

For each cell:

- Cloud masking → Proceed if non cloudy pixels > 35%
- Set upper limit for aerosol loading from the darkest pixel.
- Estimation of AOT550:
  - Inversion of clusters of 5 reference pixels.
  - Trade-off between accuracy and time can be selected by the user.
II. Algorithm Theoretical Background

- Based on the inversion of the ratio

\[ R = \frac{L_{15}}{L_{14}} \]

- Merit Function:

\[ \chi(CWV) = R_{\text{SEN}}^{\text{CWV}} - R_{\text{SIM}}^{\text{CWV}} \]

- Surface reflectance assumed to be linear in the 865-900nm spectral range.

- 1-D Optimization (Brent’s algorithm)
II. Algorithm Theoretical Background

**Surface reflectance retrieval**

- TOA radiance modeled assuming Lambertian reflectance for the target:

\[
L_{\text{TOA}} = L_0 + \frac{1}{\pi} \rho_s (E_{\text{dir}} \mu_{\text{il}} + E_{\text{dif}}) T_{\uparrow} \frac{1}{1 - S \rho_s}
\]

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

\[
\rho_s = \frac{L_{\text{TOA}} - L_0}{[(E_{\text{dir}} \mu_{\text{il}} + E_{\text{dif}}) \frac{T_{\uparrow}}{\pi}] + S[L_{\text{TOA}} - L_0]}
\]
II. Algorithm Theoretical Background

Adjacency effects

- Last step: adjacency correction

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

- Environment reflectance is averaged in a 1 x 1km\(^2\) (same order of aerosol coupling scale):

\[ \bar{\rho} = \frac{1}{N^2} \sum_{i,j=1}^{N} \rho_{i,j}^{blur}, \quad N = 3 \quad \text{(MERIS FR)} \]

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

II. Algorithm Theoretical Background

III. Overall Validation

IV. Results from Continental Water Bodies

V. Summary and Conclusions
III. Overall Validation

Sources of data for validation:

- Ground-based measurements from extensive field campaigns.
- Data from the AErosol RObotic NETwork (AERONET).
- Equivalent satellite-based products.

More than 200 MERIS images processed for validation
Validation - AOT retrieval

Comparison with AERONET data
Validation - AOT retrieval

Comparison with BAER

SCAPE-M

BAER

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Validation - AOT retrieval

Sample maps
Validation - CWV retrieval

Comparison with AERONET data

- Evara Station (38.57°N, -7.91°E)
  - $y = 0.261 + 0.843x$
  - $R^2 = 0.948$
  - RMSE = 0.20 g·cm$^{-2}$

- Toulouse Station (43.50°N, 1.37°E)
  - $y = 0.392 + 0.897x$
  - $R^2 = 0.918$
  - RMSE = 0.20 g·cm$^{-2}$

- Avignon Station (43.92°N, 4.88°E)
  - $y = 0.178 + 0.855x$
  - $R^2 = 0.973$
  - RMSE = 0.14 g·cm$^{-2}$

- Carpentras Station (44.08°N, 5.06°E)
  - $y = 0.500 + 0.754x$
  - $R^2 = 0.748$
  - RMSE = 0.38 g·cm$^{-2}$

- Palencia Station (41.99°N, -4.32°E)
  - $y = 0.192 + 0.980x$
  - $R^2 = 0.943$
  - RMSE = 0.18 g·cm$^{-2}$
Validation - CWV retrieval

Sample maps

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Validation - Reflectance retrieval

Comparison with CHRIS-PROBA data

ASD vs CHRIS

CHRIS vs MERIS

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Validation - Reflectance retrieval

Comparison with BAER

BAER

SCAPE-M
Validation - Reflectance retrieval

Comparison with BAER

$\lambda$~Red
Comparison with BAER

λ~Near-Infrared

Validation - Reflectance retrieval
I. Introduction

II. Algorithm Theoretical Background

III. Overall Validation

IV. Results from Continental Water Bodies

V. Summary and Conclusions
IV. Results from Continental Water Bodies

SCAPE-M applied to MERIS FR data from dedicated field campaigns at reservoirs:

- **CEDEX, Summer 2003:**
  - North-East Iberian Peninsula.
  - 4 reservoirs with ground-based reflectance measurements.
  - No perfect temporal co-location (+/- 1 day).

- **Validation of the MERIS lake water processor (BEAM), Summer 2007:**
  - Iberian Peninsula: 5 reservoirs (x1,2 points) with ground-based atmospheric and reflectance measurements.
  - Finland: 2 dates x 3 points, reflectance measurements (dark water).
Validation – Inland Water

Campaign CEDEX 2003

19-June-2003
4 Reservoirs, +/-1day
Validation – Inland Water

Campaign CEDEX 2003

Tremp

Graph showing reflectance vs. wavelength.
Validation – Inland Water

Campaign CEDEX 2003

Terradets
Validation – Inland Water

Campaign CEDEX 2003

Canelles

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Validation – Inland Water

Campaign CEDEX 2003

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Validation – Inland Water

Campaign CEDEX 2003

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Validation – Inland Water

Campaign “MERIS Lakes” 2007

- Almendra
- Rosarito
- Alcántara
- Iznájar

(“Cuerda del Pozo” and “Albufera”)

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Validation – Inland Water

Campaign “MERIS Lakes” 2007

6-June-2007
Albufera

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Campaign “MERIS Lakes” 2007

28-June-2007
Cuerda del Pozo
Validation – Inland Water

Campaign “MERIS Lakes” 2007

4-July-2007
Iznájar
Validation – Inland Water

Campaign “MERIS Lakes” 2007

13-July-2007
Rosarito

2nd MERIS/(A)ATSR User Workshop – ESRIN 22-26 September 2008
Comparison with
BEAM Eutrophic Lakes Processor
Validation – Inland Water

Comparison with BEAM Eutrophic Lakes Processor
Campaign “Lake Processor” 2007
Finland lakes

Päijäne, 4-06-2007

Pyhäjärvi, 23-08-2007

Courtesy of Sampsa Koponen
Helsinki University of Technology
I. Introduction

II. Algorithm Theoretical Background

III. Overall Validation

IV. Results from Continental Water Bodies

V. Summary and Conclusions
V. Summary and Conclusions

- SCAPE-M: atmospheric processor for MERIS L1b data over land and inland waters.

- Overall validation over land: >200 MERIS FR/RR images with ground-based measurements, AERONET data & other satellite-based products.

- Typical RMSE of AOT550~0.05 and CWV~0.2 gcm\(^{-2}\)

- Reflectance: good comparison with ground measurements, C/P & BAER.
V. Summary and Conclusions

- Validation extended to continental waters.
- Good performance in the retrieval of both reflectance level and spectral shape at eutrophic waters.
- Large reflectance errors at blue and NIR over dark water ($\rho \sim 1\%$).

Future?

- Validation over coastal waters remaining.
- Room for improvement: sun-glint, polarisation & adjacency correction. Benefit from ESA processors?
Thank you for your attention!
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