Aerosol Optical Thickness Retrieval Over Land: The Atmospheric Correction Based on MERIS L2 Reflectance

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Overview

Why aerosol retrieval?
Why for L2 data?
The BAER (Bremen Aerosol Retrieval) approach for L2 reflectance.
Simultaneous retrieval of AOT and surface reflectance
Results of AOT investigations
Validation
Conclusion, Outlook
Aerosol information is required:

- **Atmospheric correction for surface remote sensing**  
  (Ocean and Land. Required for land use applications)

- Climate research  
  (direct and indirect aerosol effects, aerosol cloud interaction)

- Environmental control  
  (pollution, transport of pollutions)

Satellite observations from MERIS L1 and L2 can provide:

- Regional and temporal distribution of AOT and aerosol type
- Aerosol remote sensing also over land surfaces
- Most sources are over land  
  (anthropogenic pollution, mineral dust, biomass burning)

- Investigation of land use and its variation.
This project considers MERIS L2 reflectance data.

Over land surface:

Reflectance in the L2 data product is corrected for Rayleigh scattering only.
Aerosol effects are NOT considered.

Requirement for L2 data over land: complete the atmospheric correction of the L2 reflectance data by

1. Retrieval of spectral AOT for the atmospheric correction:
   BAER (Bremen Aerosol Retrieval)

2. Application of AOT within an atmospheric correction procedure
   SMAC (Simplified Method for Atmospheric Correction),
   BAER-AC (Integrated within BAER)
General Approach

TOA-Reflectance, Kaufman et al. 1997
\[ \rho_{TOA}(z_0, z_S, \phi) = \rho_{Black}(z_0, z_S, \phi, \delta_{Aer}, \delta_{Ray}, p(\theta), \omega_0, 0) \]
\[ + \frac{t_{tot}(z_0)t_{tot}(z_S)A_{Surf}(z_0, z_S)}{1 - A_{Surf}(z_0, z_S)r_{Hem}(\delta_{tot}, g)} \]

No separation between atmospheric constituents, only surface

Separation for aerosol effect required:

1. Subtraction of Rayleigh path reflectance
\[ \rho_{TOA}(z_0, z_S, \phi) - \rho_{Ray}(z_0, z_S, \phi, p, 0) = \rho_{Aer}(z_0, z_S, \phi, \delta_{Aer}, p_{Aer}(\theta), \omega_0, 0) \]
\[ + \frac{t_{tot}(z_0)t_{tot}(z_S)A_{Surf}(z_0, z_S)}{1 - A_{Surf}(z_0, z_S)r_{Hem}(\delta_{tot}, g)} \]

➢ Remains the combined effect of aerosol and surface.
\[ \rho_{Aer}(z_0, z_S, \phi, p_{Aer}(\theta), \omega_0, 0) = \rho_{TOA}(z_0, z_S, \phi) - \rho_{Ray}(z_0, z_S, \phi, p, 0) - \frac{t_{tot}(z_0)t_{tot}(z_S)A_{Surf}}{1 - A_{Surf}r_{hem}(\delta_{tot}, g)} \]
For L2 reflectance data Rayleigh correction is made:

\[
\rho^{Aer}(z_0, z_S, \phi, p_{Aer}(\theta), \omega_0, 0) = \rho^{L2}(z_0, z_S, \phi) - \frac{t_{AER}(z_0)t_{AER}(z_S)A_{Surf}}{1 - A_{Surf}r_{HEM}(\delta_{AER}, g)}
\]

Total transmission and hemispheric reflectance are needed for aerosol effect

→ First guess for AOT required
→ Assumption of 'black surface'
→ Then iterative improvement of AOT values by BAER

Atmospheric Correction

for known AOT corrected surface reflectance (implemented in BAER):

\[
A_{Surf} = \rho_{SURF}(z_0, z_S, \phi) \approx \frac{\rho^{L2}(z_0, z_S, \phi) - \rho^{Aer}(z_0, z_S, \phi, \delta_{AER}, p_{Aer}(\theta), \omega_0, 0)}{t_{AER}(z_0)t_{AER}(z_S)}
\]
BAER consists of:

1. Estimation of surface reflectance (for 'dark targets') by a linear mixing model of elementary surface cover types

2. Determining an aerosol reflectance

3. Application of LUT for AOT determination: LUT bases on aerosol parameters of LACE-98

4. Smoothing the spectral AOT by variation of spectral surface reflectance

5. Atmospheric correction
Surface Reflectance Model

**Approaches:**

1. Inter-correlation (*Kaufman et al.*)
2. Restriction to DDV (*Santer et al.*)
3. Linear mixing of basic surface types, (BAER)

**Over Land:**

\[
\rho_{\text{Surf}}(\lambda) = C_{\text{Veg}} \rho_{\text{Veg}}(\lambda) + (1 - C_{\text{Veg}}) \rho_{\text{Soil}}(\lambda)
\]

- Bare soil
- Green vegetation

**Disturbing Effects**

- Channels: AVHRR, SeaWIFS, OCTS, MOS
- Gaseous Absorbers: Oxygen, Water Vapour
- Surface Reflectance: Vegetation, Bare Soil

**Over Ocean:**

\[
\rho_{\text{Surf}} = (1 - c_{\text{Pigment}}) \cdot \rho_{\text{Clear}} + c_{\text{Pigment}} \cdot \rho_{\text{Coastal}} + \text{Fresnel reflectance}
\]

- Clear Water
- Coastal Water

\[C_{\text{Pigment}} = f(\text{NDPI})\]
AOT of channels 1 – 7 directly retrieved

spectral features can be recognized:

• Spectral slope of AOT and Angström $\alpha$.

• Extrapolation for all MERIS channels enabled

Improvements: disturbance by vegetation peak in channel 5 is reduced (lower weights for this channel)
AOT - Validation

Two methods used:
comparison

with ground-based AERONET data
\[ \text{AOT}(0.412 \, \mu m) = 1.007 \times \text{AOT}_{\text{AERONET}} + 0.007 \]

with L2 aerosol product from DDV
\[ \text{AOT}(0.412 \, \mu m) = 0.976 \times \text{AOT}_{\text{DDV}} + 0.179 \]
# AOT Comparison

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<tr>
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<th>BAER</th>
<th>DDV</th>
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<tbody>
<tr>
<td>AOT over land:</td>
<td>&gt; 60 % of land surfaces</td>
<td>&lt; 10 % of land surface</td>
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<tr>
<td>Magnitude of AOT:</td>
<td>comparable</td>
<td>comparable</td>
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<tr>
<td></td>
<td>$\text{AOT}<em>{BAER} &gt; \text{AOT}</em>{DDV}$</td>
<td></td>
</tr>
<tr>
<td>Aerosol type</td>
<td>fixed for scene</td>
<td>variable (best fit)</td>
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<tr>
<td>Known issues:</td>
<td>bias on bright bare soils in magnitude and spectral slope of AOT</td>
<td>no AOT</td>
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Atmospheric Correction
Routine associated with BAER

\[ \rho_{\text{SURF}}(z_0, z_S, \phi) \approx \frac{\rho(z_0, z_S, \phi) - \rho^{\text{Aer}}(z_0, z_S, \phi, \delta_{\text{AER}}, p_{\text{Aer}}(\theta), \omega_0, 0)}{t_{\text{AER}}(z_0) t_{\text{AER}}(z_S)} \]
Surface Reflectance

Comparison of atmospherically corrected surface reflectance of 0.665 and 0.865 µm vs. rectified RED and NIR reflectance of L2 product
RGB from L2 reflectance product without aerosol correction

RGB from L2 data with BAER – SMAC AC (continental aerosol model)

Thin clouds, no continental aerosol
Conclusions

➢ For the most areas in Europe the separation between aerosol and surface properties can be achieved and AOT can be derived.

➢ The algorithm gives now for MERIS for the channels 1 – 7 (412 - 665 nm) useful and comparable results with AERONET observations and L2 DDV aerosol product.

➢ For higher channels (≥ 8) AOT must be extrapolated, using Angström power law.

➢ Spectral surface reflectance obtained simultaneously with AOT retrieval. Two approaches for aerosol correction are applicable: SMAC processor and correction by BAER-AC

Surface reflectance is obtained by correction TOA reflectance for Rayleigh path reflectance and aerosol reflectance, using extrapolations.

Outlook

➢ Developement and application of LUT for various surface conditions