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Session 5

MERIS Atmosphere and Land Products validation
MERIS Atmosphere and Land Products Validation

Introduction

M. Rast & P. Goryl

No presentation available
MERIS AEROSOL PRODUCT VALIDATION OVER LAND

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(2) Université du Littoral, France
**The product**

**Method**
- Aerosol Optical path Reflectance retrieved at 412, 443 and 70 nm over Dark Dense Vegetation (DDV)
- DDV detected using threshold on Atmospherically Resistant Vegetation Index (ARVI)
- Aerosol models: index of refraction of 1.33, 1.44 or 1.55 (with little absorption) and Junge size distribution with Angstroem exponent of 0 to 1.5 by step of 0.5

**Outputs**
- Aerosol Optical Thickness at 865 nm
- Epsilon: spectral dependence of the aerosol path reflectance between 765 and 865 nm
Available Data

- 278 Level 2 MERIS images
  - 122 Images in coincidence with AERONET measurement
- 1089 Level 1B MERIS images
  - 409 Images in coincidence with AERONET measurement
- 24 AERONET sites covering 7 biome out of 10
Validation Approach

- DATA BASE set up for the level 1B, level 2 MERIS products
- DATA BASE set up for the AERONET measurements (Aerosol optical thickness, Angström coefficient, Radiance measurement in the principle plane) over 24 sites since 1997
- Comparison of the level 2 MERIS product with AERONET network
- Use of breadboard algorithm to produce in-house 1B product and to increase number of match-up and test some possible improvements
- Validation of the use of the AERONET product (Aerosol optical thickness and angström coefficient) to calculate the aerosol scattering functions used in the atmospheric correction scheme
\[ \varepsilon \rightarrow 1 \rightarrow 1.2 \]
MERIS Level 2 product vs. AERONET over all AERONET sites

100 RR pixels boxes

10 RR pixels boxes

MAVT MERIS Workshop, Frascati 2003
MERIS Level 2 product vs. AERONET over all AERONET sites

lev2-100-pix-i2 ddv>0.000, cl<1.000

\[ y = 1.1756 + 0.3050 \times \]

\[ R = 0.0342 \]

lev2-010-pix-i2 ddv>0.000, cl<1.000

\[ y = 0.4932 + 1.0337 \times \]

\[ R = 0.1769 \]

100 RR pixels boxes

10 RR pixels boxes

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2003
MERIS Level 2 product vs. AERONET over all AERONET sites

100 RR pixels boxes

10 RR pixels boxes

MAVT MERIS Workshop, Frascati 2003
Filtering data:
- Dark dense vegetation ratio greater than 5%
- Cloud cover smaller than 50%

MERIS Level 2 product VS AERONET over all AERONET sites
Filtering data:
- Dark dense vegetation ratio greater than 5%
- Cloud cover smaller than 50%

MERIS Level 2 product VS AERONET over ALTA FLORESTA (Brazil)
Filtering data:
- Dark dense vegetation ratio greater than 5%
- Cloud cover smaller than 50%

MERIS Level 2 product VS AERONET over ISPRA (Italy)
Cloud Shadow Problem

Scene 1

Scene 2

Rome Tor Vergata

Classified as DDV

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2003
Cloud shadow filter

Reflectance in the visible

Reflectance at 865 nm

![Graphs showing reflectance](image)
Cloud shadow screening

\[ y = 0.1285 + 0.5977 \times \]
\[ R = 0.4826 \]

\[ y = 0.1330 + 0.8052 \times \]
\[ R = 0.4814 \]
AOT(865nm) is averaged as level 3
MERIS VS MODIS

MODIS validation over similar list of sites

Graphs showing correlations and statistical values for MODIS validation.
Refractive index climatology (GSFC)

GSFC

M=1.55
M=1.44
M=1.33

AERONET

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100-pix-ii $ddv > 0.010$, $cl < 0.500$

$y = -0.0153 + 1.1967 \cdot x$

$R = 0.8648$
Validation of the Junge power law to calculate the ASF level 2 products

AERONET data base

Principal plane radiance measurement

Filtering

Coincidences at 443, 670 and 870 nm since 1997

Filtering

Stable day

AOT 443, 670 870 nm Angström coefficient

Radiative transfer code

M= 1.33; 1.44; 1.55

NCEP meteo data

Simulated radiance in the principal plane

AOT and α

Comparison in the backscatter region

Θ=90,100,110,120,130,140 and 150 °

λ=440, 670 and 865 nm

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Comparison simulated and measured radiance

670 nm  
GSFC  
440 nm

Scattering angle

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2003
Uncertainties on the aerosol optical thickness

![Graph showing relative differences in aerosol optical thickness](image)

- **870 nm**
- **670 nm**
- **440 nm**
- **120°**
- **140°**

**Δτ/τ (%)**

- **1σ**
- **2σ**
- **3σ**

**Date**
- **09/02**
- **12/02**
- **03/03**
- **06/03**
- **10/03**

**Scattering Angle**
- **90°**
- **100°**
- **110°**
- **120°**
- **130°**
- **140°**
- **150°**
- **160°**
- **170°**
- **180°**

**GSFC** **ALTA FLORESTA** **ISPRA**

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Visibility > 50km and DDV > 3% : 24 scenes -> 14 are useful
<table>
<thead>
<tr>
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<th>c0 412nm</th>
<th>c1 412nm</th>
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**SKUKUZA**

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**GSFC**

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Problem of seasonal variation of the biome

GSFC, 16/09/2003

September DDV model  August DDV model
MERIS Level 2 product VS AERONET over GSFC (east USA)

Filtering data:
- Dark dense vegetation ratio greater than 5%
- Cloud cover smaller than 50%

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Conclusions

- AOT at 443 nm in good agreement with AERONET data
- Junge size distribution well adapted
- Aerosol product spatial cover limited by the ARVI based detection method
- AOT at 670 nm and consequentially $\varepsilon$ and AOT at 865 nm bad retrieval
Recommendations

- Implement cloud shadow filter
- Implement linear dependence of DDV reflectance in the blue and red for each DDV model (20)
  - $Slope_{blue}$, $Slope_{red}$
  - $[\Delta ARVI_{min}, \Delta ARVI_{max}]$ range on which to apply the linear correction
ABSTRACT

Over land, the aerosol remote sensing is based on the observation of Dense Dark Vegetation (DDV) and this concept is applied on MERIS with a spectral index (ARVI, Atmospherically Resistant Vegetation Index) to detect the DDV and the use of the bands at 412, 443 and 670 nm to characterize the aerosols. The aerosol size distribution is assumed to follow the Junge law while the aerosol refractive index is set to 1.44. The aerosol product consists on the aerosol optical thickness (AOT) at 865 nm and on the spectral dependence of the aerosol path radiance (Epsilon coefficient $\varepsilon$ which is the ratio of the aerosol reflectance at 765 nm to that at 865 nm). The validation exercise is mostly based on the use of ground based optical measurements from the AERONET network. A classical validation of the aerosol product is conducted using the extinction measurements. A deeper validation is done in order to investigate the different assumptions used in the aerosol remote sensing module by: (i) using the ground based measurements to validate the DDV reflectance model. Atmospheric correction will be done, including the aerosols, to derive DDV reflectances for comparison to standard values. (ii) using the ground based measurements to validate the choice of the Junge size distribution by comparing the simulated radiances with this model to the measurements in the principal plane. The AOT at 865 nm is badly retrieved because of the inaccuracy of the DDV reflectance model in the red whereas the AOT at 443 nm is in good agreement with AERONET data and accuracy is comparable to what is achieved by MODIS over comparable sites. The Junge size distribution is well adapted for the representation of aerosols optical properties. The main algorithm improvement we recommend consists in introducing a dynamical DDV reflectance model that is a reflectance which varies with the ARVI of the target.

1. INTRODUCTION

Aerosol remote sensing over land from space is a difficult task because of the high reflectivity of Earth compared to the aerosol scattering signal in the back-scattering region. The technique chosen for MERIS relies on the well known Dark Dense Vegetation (DDV) concept recently generalized to the dark target concept for MODIS. The idea is to detect dark and stable targets whose reflectivity is known accurately with a simple and reliable method. For MERIS the choice was to use the Atmospherically Resistant Vegetation Index (ARVI) for detecting DDV pixels whereas MODIS team uses the capability to observe in the near-infrared at 2.1 $\mu$m for detecting dark target. In all of these techniques the two main sources of uncertainty are the accuracy of the reflectance model of the target and the aerosol models used for the computation of the aerosol scattering functions. In the case of MERIS, 20 biomes have been chosen to represent the spatial and temporal variations of the DDV concept over the globe. For each biome a set of Look Up Tables (LUTs) has been generated that gives the DDV Bidirectional Reflectance Function (BRF) and the coupling terms between the DDV and the atmosphere. From these primary LUTs, secondary ARVI thresholds LUTs have been generated using the following formula:

$$ARVI = \frac{\rho_{NIR} - \rho_{rb}}{\rho_{NIR} + \rho_{rb}}$$  \hspace{1cm} (1)

with

$$\rho_{rb} = \rho_{r} - \gamma(\rho_{b} - \rho_{r})$$  \hspace{1cm} (2)

where $\rho_{b}, \rho_{r}$ and $\rho_{NIR}$ are reflectances, corrected for molecular scattering and gaseous absorption, observed respectively in the blue, red and near-infrared channels (443, 670 and 865 nm) and $\gamma$ was set to 1.3, a value that reduces sensitivity of ARVI to aerosol amount. ARVI thresholds have been computed for DDV and an aerosol layer with a given optical thickness and a given aerosol. The aerosol characterisation is based on standard aerosol models. For MERIS the 12 models used initially for POLDER aerosol remote sensing over land. They are defined by 4 values of the Angström coefficient $\alpha$ (0.0, 0.5, 1.0, and 1.5) and 3 values for the real part of the refractive index $m$ (1.33, 1.44 and 1.55). The value $\alpha=0$ corresponds to large particles such as Saharan dust over arid region and great values of $\alpha$ correspond to small particles such as smoke particles. At the present time a reference to aerosol climatology is mandatory to set the aerosol refractive index. Optical thicknesses $\tau$ in the red and in the blue are retrieved for each Angström coefficient. Finally,
the model for which the Angström coefficient is the closest to the one obtained from the \( \tau_e \) retrieval is chosen. Then the aerosol level 2 product is calculated, that is the aerosol optical thickness in the near infrared \( \tau_a(865\text{nm}) \) and the \( \varepsilon \) coefficient which has the same meaning that the one retrieved over ocean (ratio of the aerosol reflectance between the red and the near infrared).

We present here the first results of the validation of MERIS aerosol product we obtain in 2003 using the AERONET network measurements. After the dataset description, a first part is dealing with the direct comparison of MERIS level 2 products with AERONET coincident data. Then we assess the robustness of the DDV detection with the ARVI threshold and show how to discard false DDV pixels. In a third part we demonstrate that the Junge Size Distribution is well suited to represent aerosol optical properties and thus that the choice of this particular size distribution does not affect the aerosol product accuracy. Finally we give some examples of the main problem affecting the aerosol product, i.e. the variation of the DDV reflectance with ARVI whatever the DDV model or the season. The overall approach for a correction of this effect is discussed and some recommendations for algorithm improvements are given in the final section.

2. DATA

2.1 AERONET

The AERONET database provides continuous monitoring of the aerosols columnar optical properties and also inverted microphysical parameters for various sites around the world (see Table 1 for the selected stations). We selected some representative sites with the following criteria:

- Getting a high number of coincident data with MERIS overpass.
- Covering various biome types and density to verify the robustness of the DDV concept.
- Covering various aerosol types to validate the aerosol models used in the MERIS level 2 processor.

We started by downloading the Aerosol Optical Thickness (AOT) product for each processing level, i.e., 1, 1.5 and 2 for the direct comparison with the MERIS aerosol product. For the validation of the aerosol model, we fetched the sky radiances in the solar principal plane (PPL). Level 1 data in AERONET terminology correspond to raw data, level 1.5 correspond to automatically cloud screened data, and level 2 correspond to quality assured data with the final calibration applied. For this study, we only use level 1.5 and 2 data. For the AOT in the visible, the accuracy is claimed to be less than 0.01 whereas the radiances should be calibrated to better than 5%.\(^7\)

2.2 MERIS

We get Reduced Resolution level 1b MERIS data via a routinely ftp pull protocol on the GKSS server since end of 2002 and Full Resolution level 1b via regular mail. Up to now more than 1000 images have been archived in our database. The quality of the data is excellent. The only problem is that we do not have any match-up for few sites such as Oostende, Lille, Egbert, Ouagadougou or Kanpur, thus undersampling the African and Asian DDV and aerosols models. A breadboard of the MERIS algorithm has been developed for validation purposes and mainly to derive level-2 products from these level-1B data. It follows the latest available version of the DPM (DPM i6r1 of 28 March 2003, PO-TN-MEL-GS-0006) but it is also able to include several new features and to provide more outputs such as the optical thickness at 443nm and the Angström coefficient. MERIS level 2 data have been also collected. Till now, more than 250 images are available for this study but they unfortunately don’t cover all the measurement sites.

3. PRODUCT VALIDATION

3.1 Methodology

The validation of the aerosols products retrieved from MERIS is mainly based on the comparison with the products derived from the ground based CIMEL instruments of AERONET. These data are archived in a data base. The parameters of high importance in regards with this work package are the aerosol optical thickness given at several wavelengths and the Angström coefficient. The comparison between MERIS and ground based measurements is not straightforward because of the co-location problem. The so-called co-location problem comes from the comparison of a spatial measurement made at one moment (as for a satellite) with temporal measurements made at one location (time series). Comparison is then possible if, at least, one CIMEL measurement is performed within an interval \( \Delta T \) of 30 minutes around the satellite overpass time \( t_0 \). Different values of this interval can easily be implemented in the data base. Finally if during this interval of time more than one measurement is found, the averaged value and the standard deviation are calculated.
Table 1: List of AERONET measurement sites selected for this study with their longitude, latitude and their DDV model and aerosol type.

<table>
<thead>
<tr>
<th>Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th>DDV model/aerosol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angiola</td>
<td>-119.54</td>
<td>35.95</td>
<td>Mid latitude North America West/coastal-urban</td>
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<tr>
<td>Rio Branco</td>
<td>-67.87</td>
<td>-9.96</td>
<td>Equatorial America/continental-biomass burning</td>
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<td>Stennis</td>
<td>-89.62</td>
<td>30.37</td>
<td>Tropical America/coastal</td>
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<tr>
<td>Bragansa</td>
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<td>-0.83</td>
<td>Equatorial America/continental-biomass burning</td>
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<td>Bordeaux</td>
<td>-0.58</td>
<td>44.79</td>
<td>Mid latitude Europe/coastal-urban</td>
</tr>
<tr>
<td>Kanpur</td>
<td>80.35</td>
<td>26.45</td>
<td>Tropical Asia /urban</td>
</tr>
<tr>
<td>Rome Tor Vergata</td>
<td>12.65</td>
<td>41.84</td>
<td>Mid latitude Europe/coastal-urban</td>
</tr>
<tr>
<td>Alta Floresta</td>
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<td>-9.92</td>
<td>Equatorial America/continental-biomass burning</td>
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<td>GSFC</td>
<td>-76.88</td>
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<td>Wallops</td>
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<td>Skukuza</td>
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<td>Oostende</td>
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<td>51.23</td>
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The comparison becomes also trickier because aerosols properties over land can not always be retrieved for every pixel. Pixels must be cloud free and must reflect poorly (classified as DDV). To increase the number of possible comparison, aerosol products over a station is given for areas of different sizes. The size of the area is given by $\Delta X \times \Delta X$ where $\Delta X$ can be equal to 10 or 100 pixels. For each area, the mean value and the standard deviation of the aerosol product is calculated. Until now the data base is composed of MERIS and CIMEL data for each selected site and for the period from October 2002 to beginning of October 2003.

3.2. Comparison between AERONET and MERIS

3.1.1 Level-2 products

Figure 1 shows the optical thickness as derived from AERONET at 865 nm as a function of the optical thickness as retrieved from MERIS-L2 averaged over respectively 100x100 and 10x10 pixels. Errors bars in the plot are spatial and temporal standard deviations. Results are not correlated at all at the scale of 10 pixels. Even if a weak correlation can be found at the larger scale; results from MERIS are not in agreements with AERONET measurements. MERIS retrievals tend to be greater (from a factor 3-4 on average) than AERONET optical thickness. The spatial variability of the retrieved optical thickness is very high. Results are not significantly better when we reject cases with high cloud contamination and low DDV pixels presence (not shown). The Epsilon coefficient ($\varepsilon$) can be compared with the Angström coefficient which is a product from AERONET. Figure 2 illustrates the lack of correlation between the Angström coefficient and the Epsilon coefficient.

3.1.2 Aerosol optical thickness at 443nm

Accepting only cases with at least more than 1% identified as DDV, AERONET optical thicknesses at 440 nm are correlated with MERIS optical thicknesses at 443 nm (Figure 3). Results are significantly better at the scale of 10x10pixels. The slope of the linear regression is 0.98 ($\pm0.16$ taking into account spatial and temporal variability)) with an intercept of 0.018 ($\pm0.041$) with an acceptable correlation factor of 0.76 whereas, at 100x100 pixels, the slope is 1.24 ($\pm0.32$) with an intercept of 0.014 ($\pm0.080$) and a correlation factor of 0.80. Better results at the smaller scale are explained by the effect that the pixels close to the station are more representative of the ground based measurements. Figure 3 contains more match-ups since all level 1B archive was processed whereas in figures 1 and 2 only official level 2 products were analysed. These results are comparable to those obtained with MODIS as shown in Figure 4.
Fig. 1: Optical thickness at 865nm as derived from CIMEL (AERONET) versus the optical thickness retrieved from MERIS level-2 images and averaged over an area of 100x100 pixels (a) and 10x10 pixels (b) around the AERONET sites.

Fig. 2: Angström coefficient derived from AERONET versus the Epsilon coefficient retrieved from MERIS level-2 images and averaged over an area of 100x100 pixels (a) and 10x10 pixels (b) centred around the AERONET sites.

4. DDV DETECTION

4.1 Robustness

For some particular sun-satellite geometries and in presence of clouds, some pixels can be classified as DDV due to the shadow of the clouds. This phenomenon is illustrated by Figure 5 which represents a part of Italy during a clear sky day and a day with a high cloud cover. In the second case, we remark that a lot of DDV pixels are identified as DDV at the border of the clouds. After atmospheric corrections using AERONET data we were able to distinguish between real DDV pixels with low reflectance at 443 and 670 nm (~2%) and intermediate reflectance at 865 nm (~20 to 35 %) and “false” DDV, typically pixels located in the shadows of clouds, with low reflectance at 865 nm (<15%) and brighter than DDV in the blue (~4 to 6%). A simple test on the reflectance at 865nm is then proposed to detect shadow contamination ($\rho_{865} > 0.2$ for DDV). Figure 6 shows the effect of the cloud shadow filter on the retrieved optical thickness at 443 nm on an area of 100x100 pixels around Rome for MERIS images during the year 2003.

4.2 Limitations

4.2.1 Spatial coverage

The main limitation of the ARVI method, at least in its nominal version, is to select only very dark targets which are rare and subject to strong seasonal variation, depending on location. In figure 7 are plotted typical DDV spatial coverage versus time for 2 different biomes, i.e. equatorial forest and european forest. For Surinam the coverage is sufficient and stable along the year. It enables the monitoring of aerosols background level in the image whatever the date. For Rome, it is only the case in end spring and summer.
Fig. 3: Optical thickness at 440nm from AERONET versus optical thickness at 443nm from MERIS level1B images. Only cases with more than 1% of the pixels flagged as DDV are kept to compare with MODIS study. MERIS optical thickness is averaged over an area of 100x100 pixels (a) and 10x10 pixels (b) centred around AERONET sites.

Fig. 4: Global comparisons of MODIS and AERONET derived optical thickness at 470nm, encompassing 315 points from more than 30 AERONET sites (similar to those we chose) excluding coastal sites. (from [8])

Fig. 5: Example of DDV misclassification due to cloud shadows. RGB composite of atmospherically corrected MERIS Reduced Resolution 100x100 pixels sub-scenes at 412, 443 and 670 nm centred around Rome for a clear day (a) and a cloudy day (b). DDV classified pixels are in green.

4.2.2 Detectability
ARVI is slightly dependent upon the aerosol loading, with a decrease when the AOT increases. Consequently DDV detection is limited when the atmosphere is very turbid. An example of this effect is given in figure 8 where we show AOT maps derived from MERIS and MODIS for a close coincidence over Amazonian forest in July 2003. MERIS and MODIS are in good agreement for the region where the aerosol loading is moderate but MERIS fail to capture the large forest fire plumes because no DDV is detected there.

5. VALIDATION OF THE JUNGE SIZE DISTRIBUTION
In the MERIS aerosol retrieval procedure or atmospheric correction phase, a Junge Size Distribution (JSD, $n(r) \propto r^{-\nu}$) is assumed for the aerosol scattering functions (ASF) calculations. We used here only AERONET data to investigate this assumption. Figure 9 describes the methodology we used. Basically we compared sky radiances in the principal plane in the backscattering region simulated with a JSD and measured sky radiances at 870 nm for the three indices of refraction used in the MERIS aerosol retrieval algorithm (figure 10). The JSD is derived from the Ångström coefficient $\alpha$ measured in close coincidence with the radiance data according to $\nu = -\alpha - 3$. The relative errors made on sky radiances are directly interpreted in relative errors on aerosol optical thicknesses that would be retrieved by the MERIS algorithm.
Fig. 6: Optical thickness at 440 nm from AERONET versus optical thickness at 443 nm from MERIS without (a) and with (b) cloud shadow filter for Rome Tor Vergata. Results have been averaged over a 100x100 pixels area.

Fig. 7: DDV spatial coverage seasonal variation (% of DDV pixels within a 100x100 pixels around the AERONET site) for (a) the equatorial forest, (b) a typical European site.

Fig. 8: AOT at 865 nm maps derived from MODIS (a), MERIS (b) over Alta Floresta (Amazonia) on 15 July 2003, (c) is a RGB composite from L1B MERIS image.

We processed this way several years of data for various AERONET sites. The main findings are summarised in Figure 11 for GSFC and Alta Floresta sites. With a 1σ (respectively 2σ) confidence interval, we can say that error induced by the choice of the JSD is 15% (respect. 30%) for GSFC when the best index of refraction is chosen. For this site the best choice is often 1.33 and sometimes 1.55. This is also confirmed by comparison of MERIS derived AOT and AERONET measured AOT at 443 nm where index 1.33 gives the best linear regression between both data sets.
Fig. 9: Junge size distribution validation methodology

Fig. 10: Simulated sky radiances (normalised to an extraterrestrial solar irradiance set to $\pi$) for three aerosol refractive indices (lines) and measured (cross) by AERONET at 870 nm versus the scattering angle in the principal plane. GSFC 14/05/97 11:54 UTC.

(a) G. (215 days analysed), (b) Alta Floresta.(60 days analysed)
6. VALIDATION OF THE DDV REFLECTANCE

In order to validate the DDV reflectance models and to find a way to extend the dark target approach to brighter targets we atmospherically corrected 100x100 sub-scenes using AERONET aerosol information and compared to the DDV reflectances stored in the Look Up Tables (LUTs). We kept an image subset for clear days (\(\tau_{443} < 0.15\)) to minimize atmospheric corrections errors and residual influence of aerosol on ARVI. Indeed the surface reflectance is the critical parameter for aerosol remote sensing over land and it has to be determined as precisely as possible. MERIS has
excellent radiometric performances so it is well adapted to improve surface parameters. DDV LUT’s currently used were derived from POLDER. Whereas POLDER data were very useful for the determination of Bidirectional Reflectance Distribution Functions (BRDF), MERIS should help to normalise these functions and get BRF. A typical example of surface reflectance $\rho_s$ is given in Figure 12 for Brazil. There is a linear relationship between ARVI and $\rho_s$ for DDV classified pixels ($\Delta\text{ARVI} = \text{ARVI}_{\text{DDV}} - \text{ARVI}_{\text{DDV}}$) but also for non dark targets ($\Delta\text{ARVI}$ as low as -0.5). This is a strong argument to introduce dynamical DDV reflectance model based on ARVI or any other spectral index. It should improve the aerosol model characterisation since red reflectance varies a lot even for DDV and it should also improve greatly the spatial coverage of the aerosol product. For that purpose it is important to introduce new LUT’s giving the slopes (in the red and in the blue) of the linear relationships for each DDV model and the range $[\Delta\text{ARVI}_{\text{min}}, \Delta\text{ARVI}_{\text{max}}]$ on which the linear correction has to be applied.

CONCLUSIONS AND RECOMMENDATIONS

The core of the aerosol retrieval algorithm over land is validated since it is able to confidently detect dark target in the image and retrieve AOT in the blue with an accuracy of $0.16 \tau_a \pm 0.04$. After sensitivity studies performed with a breadboard version of the algorithm, there is still room for minor algorithm improvements (number of aerosol models for example) and LUT’s consolidation (index of refraction climatology). But, at the present time the level 2 product which consists of the AOT at 865 nm and $\varepsilon$ is not satisfying since it suffers from an inaccurate DDV reflectance model in the red. Moreover the spatial coverage of the aerosol product is inadequate for some important parts of the globe. We thus propose to set the AOT at 443 nm as an output of the level 2 product and to extend the concept of DDV to “grey targets” with a linear dependence of the surface reflectance versus ARVI. This will allow a good spatial coverage and a better aerosol model characterisation, two important points for further use of the aerosol product for atmospheric corrections of MERIS data over land.

ACKNOWLEDGEMENTS

The authors want to thank J.P. Huot and Brockmann Consult for their continuous help in obtaining numerous and tailored MERIS data. The validation work took benefit of the good availability of AERONET data and we want to thank all AERONET PI for the use of their data and specifically B. Holben and D. Tanré for a private communication about data quality of AERONET. This work was supported by ESA under Cal/Val activities (contract ESTEC No 16837/02/NL/FF).

REFERENCES

Surface Pressure Product accuracy w.r.t cloud flagging

D. Ramon (1), L. Cazier (1) and R. Santer (2)
HYGEOS, France
Université du Littoral, France
Land product characterisation

\[ \Delta P = P(z=0) \cdot \exp(-z/8340.) - P_{O2} \]

- ECMWF
  1. accuracy
  2. resolution

- DEM
  1. accuracy
  2. resolution
  3. roughness

- DEM
  1. spectral data
  2. radiative transfer
  3. roughness
\[ y = a \cdot \exp\left(-\frac{(x-b)^2}{2c^2}\right) \]

- \( b = 1.93745 \) hPa
- \( c = 19.4038 \) hPa

MAVT MERIS Workshop,
Frascati 2003
El Arenosillo 18/09/2003

\[ y = a \cdot \exp(-\frac{(x-b)^2}{2 \cdot c^2}) \]

\[ b = -5.82115; c = 17.6615 \]
BalBina (Amazonia) 16/09/2003

\[ y = a \exp((-x-b)^2/(2c^2)) \]

\[ b = 1.93745 \text{ hPa}; \ c = 19.4038 \text{ hPa} \]
Retrieved surface pressure for 3 images acquired on 9th and 10th June 2003 above North Africa at 10:35, 06:42 and 08:23 UT respectively. The color scale ranges from 850 to 1050 hPa. Water surfaces, clouds and aerosol dust show a low apparent pressure. Land surfaces and sun glint show high apparent pressure.

MAVT MERIS Workshop,
Frscati 2003
Corrective factor for the coupling between absorption and scattering as a function of the apparent reflectance at 753 nm (left) for several polynomial index (spectral shift index) $m : [2;2.3]$ and barometric pressure $: [1000;1030 \ hPa]$), fitted $C$ used for surface pressure calculation (right).
Barometric pressure – oxygen pressure including C corrective factors. The magenta lines correspond to an air mass of 2.3, the region with smaller air mass is below these lines. The color scale ranges from -200 hPa to 100 hPa.

MAVT MERIS Workshop,
Frascati 2003
Conclusions

- Over land Surface Pressure accurate enough to flag thin clouds
- Over water it does not work as it is
- Simple C corrective factors improves the situation but not enough.
Recommendations

• Switch on Pressure for classification over land
• Need for a thin clouds flag over water.
Validation of biophysical products derived from MERIS over VALERI sites

F. Baret\textsuperscript{1}, S. Garrigues\textsuperscript{1}, D. Béal\textsuperscript{1},
G. Derive\textsuperscript{1}, C. Bacour\textsuperscript{1}, & M. Weiss\textsuperscript{2}

\textsuperscript{1} INRA-CSE, Avignon, France
\textsuperscript{2} Noveltis, Toulouse, France

fAPAR estimates derived from MERIS observations using the MGVI are now available. New products are being developed including the leaf area index (LAI), the cover fraction (fCover) and the chlorophyll content integrated over the canopy (LAI.Cab). have been developed for the MERIS sensor. These products will be compared to estimates derived from ground measurements. For this purpose, few VALERI sites have been considered. Each site is about 3×3 km\textsuperscript{2}. On these sites, the biophysical variables have been measured over 30 to 50 Elementary sampling units (ESU) using LAI2000 or hemispherical camera devices. An ESU represents an area of 20-60m diameter. A high resolution SPOT image is used to extend the local measurements over the ESUS to the whole site using empirical transfer functions and co-kriging techniques. This allows to get a high spatial resolution image of the considered biophysical variables that can be degraded to match the MERIS spatial resolution.

Comparison between MERIS derived biophysical products and that from the VALERI sites is discussed with due attention to the possible sources of uncertainties.

Contact author: F. Baret, baret@avignon.inra.fr
Validation of biophysical products derived from MERIS over VALERI sites

F. Baret¹, S. Garrigues¹, D. Béal¹, G. Derive¹, C. Bacour¹, & M. Weiss²

¹INRA-CSE, Avignon, France
²Noveltis, Toulouse, France

Project funded by CNES; MERIS data provided by ESA
Objectives

Compare MERIS Products to independently derived similar quantities
Currently only fAPAR (MGVI)

• Compare fAPAR products between:
  – MERIS
  – MODIS
  – VEGETATION
• Compare with ground measurements:
  – VALERI on Alpilles site
• Present new MERIS products
The study area

4 test sites 3x3km²
The Satellite Data

- **MERIS** (L2 products 1km)
  - MGVI (Gobron et al. 2000)
- **MODIS** (L2 products 1km)
  - ATBD-15 daily fAPAR
- **VEGETATION** (L2 products 1km)
  - fAPAR derived from NDVI (Weiss et al., 2002)

La Crau  Alpilles  Moules  Bonaud
Comparison between sensors

La Crau

Bonaud

Moules

Alpilles

MODIS

VEGETATION

MERIS

\[ f_{APAR} \] vs. Days Of Year (2002)

MERIS MAVT, Frascati 20-24 October 2003

5/12
Conclusion for relative comparison

- Temporal consistency OK
- Large differences between sensors:
  - MODIS: large over-estimation
  - MERIS OK except Bonaud?
- Need
  - additional test sites such as the CYTTARES network
  - Validation with field measurements
Validation with field measurements
The case of the Alpilles site
Generating medium spatial resolution fAPAR

Hemispherical photos

12 photos For each ESU

Colocated Kriging

Reflectance over each ESU

Variogramme

SPOT Image

Medium spatial Resolution fAPAR

High spatial Resolution fAPAR map

Registration Aggregation

Transfer function Established over 30-50 ESUs

RMSE=0.15

Estimated fAPAR

Measured fAPAR

fAPAR=a.R_{450}+b.R_{645}+c.R_{835}+d.R_{1640}+e

Variogram distance (meter)

MERIS MAVT, Frascati 20-24 October 2003

8/12
Validation of fAPAR over Alpilles

- **MODIS**: large range of variation
  Apparently over-estimation
  (consistent with other observations)

- **VEGETATION**: empirical relationship with NDVI
  Good agreement

- **MERIS**: smaller range of variation
  Good agreement

Different dates (colors) for single 1km² pixels and the 3 sensors (symbols)
Actual distribution of VALERI sites

17 sites available over 2002-2003…
…but need resources to be timely processed

MERIS MAVT, Frascati  20-24 October 2003
LAI, fCover, LAI.Cab Products under development

Neural network approach

To be also validated!
Conclusions

- **Limits of the current exercise**
  - One site/period

- **Perspectives**
  - *Intercomparison* of products over the CYTTARES global network of sites (around 500 sites globally distributed)
  - *Validation with field measurements*:
    - VALERI & other validation activities: more than 30 sites available
  - Extension to future products:
    - LAI, fCover, LAI.Cab: L2 FR products (ESA study)
    - LAI, fCover, fAPAR: L3 8km resolution products from the fusion of:
      - MERIS
      - VEGETATION
      - POLDER
      - AVHRR
      - MSG
MERIS AO # 516 - Land Cover Mapping at BOREAS Study Area

Baoxin Hu¹, John R. Miller¹, Pablo Zarco-Tejada², James Freemantle³, and Harold Zwick⁴

¹ Department of Earth and Atmospheric Science, York University, Canada
² Grupo de Optica Atmosferica (GOA-UVA), Universidad de Valladolid, Spain
³ Centre for Research in Earth and Space Science, York University, Canada
⁴ Macdonald, Dettwiler and Associates, Richmond, BC, Canada
1. Background and Introduction

2. Data Sets and Study Area

3. Methodology
   - Atmospheric correction to reflectance
   - Feature selection
   - Unsupervised classification

4. Results

5. Conclusions and Further Study
Background & Introduction

Field Methods (Ground Truth)

Landsat TM (geometric. model)

CASI Hyperspectral (red edge)

Saskatchewan Environment and Resource Management

Hall et al. [1995, 1997]

Zarco-Tejada & Miller [1999]

classification accuracies generally low for fen and dry conifers

red edge spectral parameters $\lambda_p, \lambda_o, \text{ and } \sigma$
Calculation of Red Edge spectral parameters using the Inverted Gaussian Model (Miller et al., 1991)

\[ R(\lambda) = R_s - (R_s - R_o) e^{-\frac{(\lambda-\lambda_o)^2}{2\sigma^2}} \]

- \( R_s \): reflectance maximum
- \( R_o \): reflectance minimum
- \( \lambda_o \): spectral position of the reflectance minimum
- \( \lambda_p \): spectral position of the curve inflection
- \( \sigma = \lambda_p - \lambda_o \): Gaussian curve width parameter

Zarco-Tejada & Miller [1999]
Background & Introduction

Work was continued by Fuentes and Gamon (CSU) with AVIRIS data using indices related to:

- Pigments
- Water content

Fuentes et al. (2001)
## Background & Introduction

<table>
<thead>
<tr>
<th>INDEX</th>
<th>FUNCTION</th>
<th>FORMULATION</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified normalized</td>
<td>Leaf chlorophyll content</td>
<td>((R_{750} - R_{705}) / (R_{750} + R_{705}))</td>
<td>Gitelson and Merzlyak (1996)</td>
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<tr>
<td>Difference vegetation index</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mNDVI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red/green ratio</td>
<td>Anthocyanins/chlorophyll</td>
<td>(R_{600-699} / R_{500-599})</td>
<td>Gamon and Surfas (1999)</td>
</tr>
<tr>
<td>Photochemical reflectance</td>
<td>Xanthophyll cycle pigment</td>
<td>((R_{831} - R_{570}) / (R_{831} + R_{570}))</td>
<td>Gamon and Surfas (1999)</td>
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<tr>
<td>index (PRI)</td>
<td>activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water band index (WBI)</td>
<td>Leaf water content</td>
<td>(R_{900} / R_{970})</td>
<td>Peñuelas et al. (1997)</td>
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<tr>
<td>Normalized difference</td>
<td>Leaf water content</td>
<td>((R_{860} - R_{1240}) / (R_{860} + R_{1240}))</td>
<td>Gao (1996)</td>
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<td>water index (NDWI)</td>
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<tr>
<td>Summed green reflectance</td>
<td>Green vegetation cover</td>
<td>(\sum_{n=500} R_{n})</td>
<td>Unpublished</td>
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<tr>
<td>Normalized difference</td>
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<tr>
<td>vegetation index (NDVI)</td>
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</tr>
</tbody>
</table>

**Fuentes et al. (2001)**
### Contingency Matrix

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Unsupervised Classification</th>
<th>SERM-FBIU Classification</th>
<th>User's Accuracy (%)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Conifers</td>
<td>C1 467 C2 282 C3 159 C4 12 C5 227 C6 23 C7 90</td>
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<td>37.0</td>
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<tr>
<td>Dry Conifers</td>
<td>C2 12 C3 83 C4 10 C5 1 C6 7 C7 5</td>
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<td>65.3</td>
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<tr>
<td>Mixed</td>
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<tr>
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<td>C4 18 C5 24 C6 123 C7 21</td>
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<td>5.7</td>
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<tr>
<td>Fen</td>
<td>C5 12 C6 87 C7 11</td>
<td></td>
<td>242</td>
<td></td>
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<tr>
<td>Water</td>
<td>C6 5 C7 18</td>
<td></td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>Disturbed</td>
<td>C7 5</td>
<td></td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>576 531 414 54 486 63 522</td>
<td></td>
<td>2646</td>
<td></td>
</tr>
</tbody>
</table>

Producer's Accuracy (%) = 81.1 15.6 22.9 38.9 24.9 33.3 56.3

**Overall Accuracy = 41.65%**

Kappa K = 0.29

### Contingency Matrix

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Unsupervised Classification</th>
<th>SERM-FBIU Classification</th>
<th>User's Accuracy (%)</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Conifers</td>
<td>C1 470 C2 209 C3 58 C4 3 C5 23 C6 7 C7 28</td>
<td></td>
<td>58.9</td>
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<tr>
<td>Dry Conifers</td>
<td>C2 0 C3 0 C4 0 C5 0 C6 0 C7 0</td>
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<tr>
<td>Mixed</td>
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<td>66.5</td>
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<td>C4 0 C5 0 C6 0 C7 0</td>
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<td>62.4</td>
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</tr>
<tr>
<td>Fen</td>
<td>C5 50 C6 121 C7 26</td>
<td></td>
<td>732</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>C6 0 C7 0</td>
<td></td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Disturbed</td>
<td>C7 2 C8 164</td>
<td></td>
<td>59.1</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>576 531 414 54 486 63 522</td>
<td></td>
<td>2646</td>
<td></td>
</tr>
</tbody>
</table>

Producer's Accuracy (%) = 81.6 0.0 68.6 0.0 94.0 0.0 78.0

**Overall Accuracy = 61.15%**

Kappa K = 0.52

### CASI & Red Edge parameters

Improved to 66-80% with additional indices

### Landsat TM & Geometrical Models
Data Sets and Study Area

- **BOREAS** (Boreal Ecosystem-Atmosphere Study) Southern Study Area (SSA)

- **MERIS** full resolution radiance data
  - October 30, 2002
  - May 10, 2003
  - August 14, 2003
  - August 30, 2003

  Used in this study. Atmospheric Correction performed from Level 1b since no correction for aerosol scattering in Level 2 MERIS data

- **SERM-FBIU** forest cover dataset (Saskatchewan Environment and Resources Management, Forestry Branch-Inventory Unit).

- **CASI** reflectance data
  - May 31, 1994
  - July 24, 1994
MERIS Data over BOREAS Study Area

May 10, 2003

August 14, 2003

SERM-FBIU forest cover

Caption:
- Green: Dry conifers
- Blue: Water
- Dark green: Wet conifers
- Red: Fen
- Pink: Deciduous
- White: Disturbed area
- Yellow: Mixed stands
CASI Data over BOREAS Study Area

May 31, 1994  July 24, 1994  SERM-FBIU forest cover

- Dry conifers
- Wet conifers
- Deciduous
- Mixed stands
- Disturbed
- Fen
Conversion to Reflectance: CAM5S

Atmospheric Parameters

Sensor Geometry

Solar Geometry

CAM5S

5S

H5S (airb.comp)

H5S+6S (10 wn)

CAM5S (Can.Adv.Mod.)

Extract parameters

Model of $\rho^*$ as function of ground $\rho$ & angles

$\rho^*(\rho_0, \theta)$

Invert model

$\rho_0(\rho^*, \theta)$

Correct Image

Conversion of $\rho^*$ to ground $\rho$ for each pixel
Reflectance Spectra: comparison with L2 Reflectance

- L2 TOA ref ESA
- Ref NoAerosol CAM5S
- Ref CAM5S
Reflectance Spectra: Comparison with CASI

Reflectance Spectra

MERIS, Jack Pine

CASI, Jack Pine

MERIS, Mixed stand

CASI, Mixed stand
Methodology: Calculation of Indices

• Feature selection
  – Optical indices sensitive to plant pigments
  – Seasonal optical indices capturing the seasonality of plant pigments
    • Optical indices in Spring (May 10)
    • Optical indices in Summer (Aug 14)

• Unsupervised classification
  – ISODATA (PCI software)
Classification Results Using MERIS Data

Classification using reflectance in August

Conifers: 30; Mixed: 74; Fen: 80; overall: 68

Classification using optical indices in August

Conifers: 45; Mixed: 69; Fen: 82; overall: 70

Classification using optical indices in Aug. + May

Conifers: 65; Mixed: 66; Fen: 78; overall: 72

SERM-FBIU forest cover

- SOBS
- SOJP
- SYJP
- SFen

Legend:
- Green: Conifers
- Red: Fen
- Yellow: Mixed stands
- White: Water
- Gray: Disturbed area
Classification Results Using CASI Data

CASI Classification

Ground truth (SERM-FBIU)

Reflectance (may)  Reflectance (may+july)  Optical indices (may)  Optical indices (may+july)

Overall classification accuracy

Dry conifers  Wet conifers  Mixed  Fen  Disturbed  Disturbed
Conclusions

• The forest classification using seasonal changes in optical indices from MERIS (May and August) shows reasonably high overall classification accuracy (72%).

• Classification using indices and red edge spectral parameters sensitive to pigment absorption obtains better results than absolute reflectance bands.

• Seasonal MERIS information improves classification accuracies

• Further work is required to validate reflectance obtained from CAM5S
Methodology: Feature Selection and Unsupervised Classification

- CAM5S Radiative Transfer Code

- Input required by CAM5S Code
  - Aerosol optical depth: measured
  - Aerosol type: continental
  - Atmospheric model: mid latitude
  - Solar geometry: calculated using location (latitude and longitude) and time
  - Sensor geometry: calculated orbit parameters and sensor pointing characteristics
  - Sensor spectral response: Gaussian response with FWHM from image header file.
Validation of MERIS water vapour measurements

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R. Bennartz\textsuperscript{2}

\textsuperscript{1}Institut für Weltraumwissenschaften, Freie Universität Berlin
\textsuperscript{2}Atmospheric and Oceanic Sciences Department, University of Wisconsin, Madison
Overview

- Example MERIS full resolution
- Validation with Microwave Water Radiometer
  - Water vapour above cloud free land surfaces
- Validation with radio soundings
  - Water vapour above cloud free land surfaces
  - Water vapour above clouds
MERIS water vapour above land – full resolution (~300 m)

True colour image taken 12th of August 2003 over Spain
Integrated water vapour (left) and true colour image (right) taken 12th of August 2003 over Spain. The image shows the confluence of Rio Jarama and Rio Tajuna in the vicinity of the Spanish city Aranjuez. The columnar water vapour increases with decreasing surface height.
Integrated water vapour (left) and surface height (right) taken 12th of August 2003 over Spain.

Due to the lower surface heights in the river valleys, the columnar water vapour increases. This is well represented by the MERIS measurements.
Comparison of MERIS derived integrated water vapour with measurements of the microwave radiometer at the ARM-SGP site.

Observation period is Nov. 2002 – August 2003
For each day, the closest MERIS pixel was compared to the MWR 5-min average closest in time to the MERIS overpass.
MERIS water vapour – radiosonde measurements

Water vapour above land

Scatter plot of columnar water vapour measurements by the Microwave Water Radiometer at the ARM-SGP site vs. MERIS measurements.

MWR data were obtained from the Atmospheric Radiation Measurement (ARM) Program sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Environmental Sciences Division.
Scatter plot of columnar water vapour measurements by radio soundings vs. MERIS measurements. Measurements are taken over Central Europe between October 2002 and August 2003.
MERIS water vapour – radiosonde measurements

Water vapour above clouds

MERIS water vapour (upper left) and cloud top pressure (upper right) and comparison with radiosounding (lower) – 13.10.2002
Scatter plot of MERIS and RS cloud top pressure (left) and water vapour above clouds (right). Measurements are taken over Central Europe between October 2002 and August 2003.
Conclusion

• MERIS water vapour measurements show high accuracy when compared to radiometer and radiosonde measurements

• High spatial resolution offers new possibilities in the investigation of water vapour fields
Validation of MERIS cloud top pressure

Rene Preusker,
Peter Albert, Jürgen Fischer

Institut für Weltraumwissenschaften
FU Berlin
Outline

• MERIS / Radiosondes
• MERIS / MODIS
• MERIS / ARM Radar
Goal:

Compare cloud top pressure from MERIS above the validation sites with the profile of cloud probability from the profile of relative humidity using a method described by Wang and Rossow [1995].

Limitations:

Time differences between radiosonde launch and satellite overpass and a limited accuracy of relative humidity measurements above clouds.
The MERIS cloud top pressure and the profile of relative humidity for a high level cloud (upper; 21. 10. 2002 above Lindenberg, Germany) and for a low level cloud (lower; 24. 10. 2002 above Oppin, Germany).
Scatter diagram of all retrieved cloud heights. The median cloud top in the 0.5° square around the radiosonde launch point was taken as the MERIS cloud top height, the error-bar is the standard deviation within this area.
MERIS cloud top pressure – MODIS

Goal:
Compare the operational cloud top pressure from TERRA/MODIS (based on CO$_2$ slicing method; Frey et al. 1999) with the cloud top pressure from MERIS by mapping MERIS and MODIS data onto a common grid.

Limitations:
Time difference between the satellite overpasses and low sensitivity of MERIS for very thin clouds.
MERIS cloud top pressure above the North sea from 20.10.2002 10:17 UTC (upper left), the corresponding MODIS cloud top pressure at 9:50 UTC (upper right) and 11:28 UTC (lower right) and the profile of relative humidity at 12:00 UTC above Herstmonceux (GB).
MERIS cloud top pressure – MODIS

Scatter diagram of the median MODIS and the median MERIS cloud top heights for all considered scenes. The error-bars are the standard deviations of each scene.
Comparison with ARM cloud radar

- 100 cases over ARM site
  - 20 cloudy
    - 17 with cloud radar working
    - 5 with single layer clouds ($\tau>5$)
Case 1: 05/01/2003

MERIS: 600hPa ± 15hPa

RADAR: 2 cloud layers at 637hPa and 569hPa
Case 2: 15/02/2003

MERIS: 820 hPa ± 10 hPa
RADAR: 820 hPa
Case 3: 22/03/2003

[Two satellite images showing weather patterns]
Case 3: 28/03/2003

MERIS: 700hPa ± 100hPa
RADAR: 575 hPa
Case 4: 03/06/2003
Case 4: 03/06/2003

MERIS: 835 hPa ± 25 hPa
RADAR: 790 hPa
Case 5 : 04/06/2003

14 UTC

16/04 16:14 UTC
Case 5: 04/06/2003

MERIS: 450hPa ± 100hPa
RADAR: 300 hPa
Case 6: 07/06/2003

MERIS: 575hPa ± 75hPa
RADAR: 580hPa
Case D: 04/04/2003
Case D: 04/04/2003

MERIS: 780hPa ± 20hPa
RADAR: 903hPa, 370hPa
Summary MERIS cloud top pressure

1. Comparisons with cloud radar allow accurate and profound investigations.
2. The comparisons support expectations from theory:
   1. For single layer clouds ctp accuracy is within 30 hPa
   2. For multi-layer clouds, the retrieved ctp is related to an „effective“ penetration depth, somewhere between the upper and the lower layers
Cloud Identification Tests

- Bright threshold
- Land: slope tests
  - cloud over bright sand
  - cloud over snow and ice
- Land and Ocean
  - 2 pressure products
  - ECMWF pressure
  - 3 differences
Cloud Identification - Land

- Cloud over bright surfaces (sand)
- Slope 1: R443 / R753
### Slope 1 Values

<table>
<thead>
<tr>
<th>Slope1</th>
<th># of misclassified pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7000</td>
<td>1159</td>
</tr>
<tr>
<td>0.7750</td>
<td>115</td>
</tr>
<tr>
<td>0.7825</td>
<td>34</td>
</tr>
<tr>
<td>0.7850</td>
<td>25</td>
</tr>
<tr>
<td>0.7875</td>
<td>16</td>
</tr>
<tr>
<td>0.7900</td>
<td>12</td>
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<tr>
<td>0.7925</td>
<td>7</td>
</tr>
<tr>
<td>0.7950</td>
<td>2</td>
</tr>
<tr>
<td>0.7965</td>
<td>2</td>
</tr>
<tr>
<td>0.7975</td>
<td>2</td>
</tr>
<tr>
<td>0.8000</td>
<td>1</td>
</tr>
<tr>
<td>0.8025</td>
<td>1</td>
</tr>
<tr>
<td>0.8050</td>
<td>1</td>
</tr>
<tr>
<td>0.8075</td>
<td>1</td>
</tr>
<tr>
<td>0.8100</td>
<td>1</td>
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<tr>
<td>0.8125</td>
<td>0</td>
</tr>
<tr>
<td>0.8075</td>
<td>1</td>
</tr>
</tbody>
</table>

### Threshold Tuning

- **RGB**
- **IPF/matchup setting**

**Slope1 = 0.70**
North Sea

Slope1 = 0.70

Slope1 = 0.75
Cloud Identification - Land

- Cloud over bright surfaces (sand)
- Slope 1: R443 / R753

Conclusion
- should be included with slope1_low threshold = 0.70
- individual scenes can be classified better with individually tuned threshold
Cloud over Ice and Snow: slope 2

\[
\text{If } (\rho_c(b_{\text{slope2}} d) > 0) \text{ then}
\]

\[
\begin{align*}
\text{SLOPE}_2 F &= \left\{ \begin{array}{ll}
\frac{\rho_c(b_{\text{slope2}} n)}{\rho_c(b_{\text{slope2}} d)} \geq \text{Slope2}_{\text{low}} \\
\frac{\rho_c(b_{\text{slope2}} n)}{\rho_c(b_{\text{slope2}} d)} \leq \text{Slope2}_{\text{high}}
\end{array} \right\} \text{ AND } \\
\text{TOAR}(b_{\text{slope2}} n, i, f) \geq \text{SATURATION}_L(b_{\text{slope2}} n) & \text{ OR } \\
\end{align*}
\]

\[
\text{else} \\
\text{SLOPE}_2 F = \text{FALSE} \\
\text{Endif}
\]
State in Aerosol Remote Sensing for Atmospheric Correction of MERIS Land Surface Products

Wolfgang von Hoyningen-Huene,
John P. Burrows,
Alexander Kokhanovsky
Institute of Environmental Physics, University of Bremen

Veronique Bruniquel,
NOVELTIS Toulouse

Peter Regner,
ESRIN

Objective
Description of the BAER Approach
Problems in Adaptation of the Algorithm from SeaWiFS to MERIS
First Results
Conclusions, Outlook

Objective

- Land surface products of MERIS require an adequate atmospheric correction for the space-borne determination of spectral properties of land surfaces.
- The variability of atmospheric disturbances in VIS and NIR is caused mainly by atmospheric aerosol.
- Atmospheric correction needs a sufficient determination of the aerosol optical thickness (AOT) over land surfaces as the main factor of variability.
- Land surfaces to investigate cannot be restricted to Dense Dark Vegetation (DDV) only, the algorithm must be more flexible.
- BAER (Bremen AErosol Retrieval) algorithm developed and tested for aerosol retrievals over land surfaces with SeaWiFS L1A data.
- Aim: Adaptation of BAER for MERIS L1 and L2 data and description in an ATBD.
Description of the BAER Approach

BAER consists of:

1. Estimation of surface reflectance (for 'dark targets') by a linear mixing model of elementar 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
Determination of Aerosol Reflectance, Theoretical Background

TOA-Reflectance, Kaufman et al. 1997

\[
\rho^{TOA}(z_0, z_S, \phi) = \rho^{Black}(z_0, z_S, \phi, \delta_{Aer}, \delta_{Ray}, \rho(\theta), \omega_0, 0) + \frac{t_{tot}(z_0)t_{tot}(z_S)A_{Surf}(z_0, z_S)}{1 - A_{Surf}(z_0, z_S)r_{Hem}(\delta_{tot}, g)}
\]

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, to be separated.

\[
\rho^{Aer}(z_0, z_S, \phi, p_{Aer}(\theta), \omega_0, 0) = \rho^{TOA}(z_0, z_S, \phi) - \rho^{Ray}(z_0, z_S, \phi, p, 0) - \frac{t_{tot}(z_0)t_{tot}(z_S)A_{Surf}}{1 - A_{Surf}r_{hem}(\delta_{tot}, g)}
\]
Separation of Surface Reflectance

Approaches:
1. Restriction to DDV
2. Linear mixing of surface types, BAER

 Disturbing Effects

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

Channels
- AVHRR
- SeaWiFS, OCTS, MOS

Gaseous Absorbers
- Oxygen
- Water Vapour

Surface Reflectance
- Vegetation
- Bare Soil

Bare soil
Green vegetation

\[
C_{Veg} = f(NDVI_{Corr})
\]

\[
A_{surf} = \rho_{Surf}
\]
BAER works successfully with SeaWiFS L1A data on GAC and LAC scale

Using SeaWiFS L1A data, AOT of 412 nm is detectable with about 20 % accuracy, AOT of 6 channels: 412, 443, 490, 510, 555, 670 nm can be derived

Formally approach transferable to MERIS
- for L1 radiance data
- or L2 TOA-reflectances

First 1:1 application with L1 data, showed
- significant differences in the results for AOT for comparable overflights of MERIS and SeaWiFS

Check for compatibility of
- instrument characteristics
- input data
- made assumptions

Preliminary Adaptations: Modification of scaling factors of the land surface reflectance model
1:1 Application of BAER with MERIS L1 data


BAER Algorithm principally applicable to MERIS too

Systematic differences in AOT between SeaWiFS and MERIS

Still larger land sea discrepancies in MERIS

Observable aerosol-cloud interaction

Reasons are different characteristics of channels, used for the determination of NDVI (MERIS > SeaWiFS)
### Differences MERIS – SeaWiFS I - Observation characteristics

<table>
<thead>
<tr>
<th>Description</th>
<th>SeaWiFS</th>
<th>MERIS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiometer</strong></td>
<td>SeaWiFS</td>
<td>MERIS</td>
</tr>
<tr>
<td><strong>Platform</strong></td>
<td>OrbView-2</td>
<td>ENVISAT</td>
</tr>
<tr>
<td><strong>Ground Resolution</strong></td>
<td>4 km</td>
<td>1.2 km (0.3 km)</td>
</tr>
<tr>
<td><strong>Coarse ((GAC, RR))</strong></td>
<td>1.1 km</td>
<td>0.3 km</td>
</tr>
<tr>
<td><strong>Fine (LAC, FR)</strong></td>
<td>0.0916 deg</td>
<td>0.019 deg</td>
</tr>
<tr>
<td><strong>IFOV</strong></td>
<td>Tilted scan</td>
<td>Nadir scan</td>
</tr>
<tr>
<td><strong>Viewing</strong></td>
<td>Filters</td>
<td>Grating</td>
</tr>
<tr>
<td><strong>Spectral Separation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of Channels</strong></td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td><strong>Signal amplification</strong></td>
<td>Dual slope sensitivity</td>
<td></td>
</tr>
</tbody>
</table>

**Consequences:**

- Higher spatial resolution
- Less mixing of different surface types
- On ocean more sun glint
- Constant sensitivity
### Differences MERIS – SeaWiFS II - Spectral

<table>
<thead>
<tr>
<th>Radiometer</th>
<th>Number of Channel</th>
<th>SeaWiFS</th>
<th>MERIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td>Aerosol (Land/Ocean)</td>
<td>1</td>
<td>412 (20)</td>
<td>412.5 (10)</td>
</tr>
<tr>
<td>Aerosol (Land/Ocean)</td>
<td>2</td>
<td>443 (20)</td>
<td>442.5 (10)</td>
</tr>
<tr>
<td>Aerosol (Land/Ocean)</td>
<td>3</td>
<td>490 (20)</td>
<td>490 (10)</td>
</tr>
<tr>
<td>Aerosol (Land/Ocean)</td>
<td>4</td>
<td>510 (20)</td>
<td>510 (10)</td>
</tr>
<tr>
<td>Aerosol (Land/Ocean)</td>
<td>5</td>
<td>555 (20)</td>
<td>560 (10)</td>
</tr>
<tr>
<td>Aerosol (Land/Ocean)</td>
<td>6</td>
<td></td>
<td>620 (10)</td>
</tr>
<tr>
<td>NDVI, Aerosol (Land/Ocean)</td>
<td>7</td>
<td>670 (20)</td>
<td>665 (10)</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td>681.3 (7.5)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td></td>
<td>705 (10)</td>
</tr>
<tr>
<td>O₂-A Band</td>
<td>10</td>
<td></td>
<td>753.8 (7.5)</td>
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<td>O₂-A Band</td>
<td>11</td>
<td></td>
<td>760 (2.5)</td>
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<tr>
<td>Aerosol (Ocean)</td>
<td>12</td>
<td>765 (40)</td>
<td>775 (15)</td>
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<tr>
<td>NDVI, Aerosol (Ocean)</td>
<td>13</td>
<td>865 (40)</td>
<td>865 (20)</td>
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<tr>
<td>WV</td>
<td>14</td>
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<td>885 (10)</td>
</tr>
<tr>
<td>WV</td>
<td>15</td>
<td></td>
<td>900 (10)</td>
</tr>
</tbody>
</table>

**Consequences:**

More channels – more information: channel 6

O₂-A channel with height information

Smaller band width – better separation of different constituents

Small wavelength shifts (chn. 5, 7, 12) – modified parameters derived (NDVI)
Modified weighting factors for land surface mixing

Now comparable AOT between both instruments from L1 data

Comparison Retrieval - Ground-based Measurements

- Channel 1 (0.412 m)
- Channel 7 (0.665 m)
L1 – L2 Data

L2-reflectance data are inconsistent between land and ocean:
Land: only Rayleigh correction is made,
Ocean: Rayleigh + Aerosol correction is made.

- Restricts the BAER algorithm with L2 data to run only over land surfaces

ToAer-Reflectance from BAER L1 < ToAer-Reflectance from L2 product,
Rayleigh correction of BAER > Rayleigh correction of L2 product

Other adaptation of scaling and mixing parameters to changed reflectance level, between L2 and BAER L1 Rayleigh corrected reflectance

Larger effort to use L2 corrected reflectance than L1 TOA reflectance.
Statistical determination of mixing parameters, validation
For the most areas in Europe the separation between aerosol and surface properties can be achieved and AOT can be derived.

The algorithm gives for the channels 1 – 4 (412 - 510 nm) useful and comparable results with SeaWiFS observations.

The accuracy can be improved by an intensive validation and fixing of the empirical scaling factors statistically.

For higher channels a higher variability of AOT occurs:

- Not fully compensated surface reflectance -> selection of better surface reflectance spectra
- Disturbing effects of small sub-pixel clouds. -> improvement of cloud screening
- Extension of LUT for specific aerosol types
- Integration of MERIS channel 6 (620 nm) into the BAER approach
- Investigation of the variability of the vegetation spectra in the range of 560 – 665 nm.
Look-up-Tables and Data

AOT - aerosol reflectance relationships by RTM

Phase function

Single scattering albedo

Experimental data from closure experiments used (ACE-2, LACE-98, INDOEX) as inputs

ACE-2 (Portugal, 1997) - marine
LACE-98 (Germany, 1998) - remote continental
INDOEX (Indian Ocean, 1999) - pollution outflow
Measurement campaigns in
Senegal (1995) - desert dust
Malaysia (Oct. 1997) - biomass burning
Smoothing

Individual determination of $\delta_{\text{Aer}}(\lambda)$ for the 6 (7) channels contain random and systematic variation around the true AOT slope of an Angström power law caused by the surface reflectance

$$\bar{\delta}_{\text{Aer}}(\lambda) = \beta \lambda^{-a}$$

$$\rho_{\text{Surf}}^{(i)}(\lambda) = \rho_{\text{Surf}}^{(i-1)}(\lambda) \cdot w(\lambda) \cdot (1 - \frac{\delta_{\text{Aer}}(\lambda) - \bar{\delta}_{\text{Aer}}(\lambda)}{\delta_{\text{Aer}}(\lambda)})$$

$$\text{RMSD} = \frac{1}{n} \sum_{i=1}^{n} \frac{\delta_{\text{Aer}}(\lambda_i) - \bar{\delta}_{\text{Aer}}(\lambda_i))^2}{\delta_{\text{Aer}}^2(\lambda_i)} \rightarrow \text{MIN}$$

Angström power law as orientation

Variation of surface reflectance and new determination of $\delta_{\text{Aer}}(\lambda)$

Criterion of smoothness ($<2 \%$)
Comparison NDVI and required Reflectance
TOA-Reflectance 2 - 5

- **MERIS TOA Refl. (0.443 µm)**
- **MERIS TOA Refl. (0.490 µm)**
- **MERIS TOA Refl. (0.510 µm)**
- **MERIS TOA Refl (0.560 µm)**
- **SeaWiFS TOA Refl. (0.443 µm)**
- **SeaWiFS TOA Refl. (0.490 µm)**
- **SeaWiFS TOA Refl. (0.510 µm)**
- **SeaWiFS TOA Refl. (0.555 µm)**