FIRST VALIDATION OF MERIS AEROSOL PRODUCT OVER LAND

Didier Ramon(1), Richard Santer(2), Jerôme Vidot(2)

1. HYGEOS, 191 rue N. Appert, 59650 Villeneuve d’Ascq, France, dr@hygeos.com
2. Université du Littoral Côte d’Opale, MREN, Av. FOCH, 62930 Wimereux, France
   santer@mren2.univ-littoral.fr

ABSTRACT

The detection of Dense Dark Vegetation (DDV) using the Atmospherically Resistant Vegetation Index (ARVI) and then the aerosol retrieval over DDV are the critical points of the land part of the processing of MERIS images implemented in the level 2 processor. We present here the first validation attempt of the MERIS aerosol product over land by checking its consistency and comparing it to AERONET data. We also applied an in-house version of the algorithm to L1B data in order to study the sensitivity of the algorithm to important parameters such as the ARVI thresholds and aerosol refractive index. SeaWiFS L1B images are also used to anticipate what will be the DDV cover throughout the year for Europe. This first validation exercise is promising and shows that the DDV approach is satisfactory in spring and summer. More extensive work is required for a full validation.

Keywords: Aerosol Remote Sensing, ENVISAT/MERIS, SeaWIFS, Dense Dark Vegetation, Atmospheric corrections over land.

1 INTRODUCTION

We were in charge of defining an algorithm for correcting MERIS images over land from atmospheric effects and providing the associated aerosol product. The image correction process itself consists of the correction from gaseous absorption and the correction from the molecular scattering. There is no correction for the aerosol scattering. However there is a further aerosol retrieval module and an accurate determination of the surface pressure from the reflectances in the oxygen absorption bands. All steps are based on simplified formulations of the signal in order to ease inversion of Top Of Atmosphere (TOA) reflectances [1].

Gaseous absorption is separated from the rest. This correction requires integrated values of gas content in the atmospheric column (mainly water vapour and Ozone) values generally available from the climatology. The Rayleigh correction is well defined and only requires knowledge of barometric pressure. This first estimation is performed via a Digital Elevation Model and the hypothesis of hydrostatic equilibrium for the lower atmosphere. Aerosol characterisation is primarily based on the inversion of the signal over dark targets for a set of standard aerosol models (here the 12 models used for POLarization and Directionality of the Earth Reflectance (POLDER). Reference to the aerosol climatology is mandatory to set the refractive index. Remaining aerosol optical thickness and slope of the Junge size distribution are determined from specific observations over DDV in the blue (412 and 443 nm) and in the red (665 nm). DDV pixels are determined using a spectral index: the Atmospheric Resistant Vegetation Index (ARVI)[2]. A pixel is flagged as DDV when its ARVI is greater than the ARVI threshold. This one is extracted from a LUT, as function of DDV model, geographical location, seasons and geometrical conditions. Standard values for DDV reflectances at 412 nm, 443 nm and 665 nm are proposed in order to retrieve the aerosol scattering functions and finally provide the aerosol product over land [3] which consists in the Aerosol Optical Thickness (AOT) at 865 nm and in the epsilon factor (ε) which is defined as the ratio of the aerosol path reflectance at 753 and 865 nm. The last output of the L2 land algorithm for MERIS is an accurate estimation of the barometric pressure from differential absorption of several close channels in the O2 A absorption bands. The ratio of TOA reflectances in those close channels are directly linked to the barometric pressure with empirical relationships and correction factors for the absorption scattering coupling effects. First examples of this product are given in a companion paper [4].

This paper is the first attempt to evaluate the quality of the aerosol product over land through: (i) consistency checks and (ii) preliminary validations. These two tasks are conducted directly on the level 2 as delivered by ESA. Then using an in-house prototype, we will conduct a sensitivity study going more deeply into the algorithm. Finally, a statistical study is proposed through the development of a level 3 product. Illustration of the DDV cover is done from SeaWiFS imagery.
2. QUALITY CHECKS

2.1 Consistency

Fig. 1. Aerosol Optical Thickness at 865 nm in the Chesapeake Bay on 23 October 2002 from L2 MERIS product. That day a coincidence with AERONET site in GSFC (39°N; 76°W) occurs.

Fig. 2. Zoom into the central part of the image of Fig. 1. Illustration of the land/water continuity of the AOT.

Fig. 3. Transect of the AOT as described in Fig. 2. Illustration of the land/water continuity of the AOT.
We analysed an image acquired on 2002-10-23 over the US east coast near the AERONET GSFC site. The AOT at 865 nm (Fig. 1) gives a good impression at first glance. The order of magnitude is correct and the spatial distribution of the aerosol doesn’t exhibit too large spatial variations. The consistency between the land and water algorithm is good except of course over highly turbid waters and for pixels just at the land-water interface. If we zoom into (Fig.2) a central region with two land/water borders, we see a good indication of the consistency of the retrieved AOT. Fig. 3 corresponds to AOT on the transect displays in Fig. 2. For the epsilon factor $\varepsilon$ (Fig. 4), we find the same variability over land than over water. Over land, it shows some rapid changes and large zone with constant values. We have to remind that $\varepsilon$ mainly describes the aerosol model and not the spectral dependence of the aerosol path radiance. The threshold effect on $\varepsilon$ mainly results on the limited number of aerosol models (4 models only). This product will be greatly improves by adding more aerosol models. This recommendation will have a little impact on the algorithm.

2.2 First validation

We compared the AOT at 865 nm for few coincidences with AERONET data for two zones (GSFC and North Italy) (Figure 5 and 6). This is a very first attempt since only four points are available. The error bars represents the spatial dispersion of MERIS data in a zone of 10 pixels around the AERONET site and an estimation of the temporal variability of the AERONET measurements. In case on cloud free cases (GSFC and Villefranche) the agreement is good. It becomes a bit noisy for the remaining two points since it was a day with high aerosol variability and frequent clouds overpass.
3. SENSITIVITY STUDY

We took advantage of an in-house version of the L2 algorithm to process L1B images and study the influence of various parameters on the aerosol product. We focus here on two: (i) the ARVI of the DDV classified pixel and (ii) the choice of the aerosol refractive index which is at the moment set to 1.44 everywhere. The L1B image taken for this study is the one shown in Fig. 5.

3.1 Sensitivity to the ARVI

Fig. 7 summarises a general tendency observed for many other MERIS images and also for other sensors like SeaWiFS or MOS [5]. First as ARVI decreases below a certain value, the AOT increases. For the nominal ARVI threshold, the mean AOT is 0.15 while if we increase the ARVI threshold by 0.07, the mean AOT is 0.11. Second, the retrieved aerosol model corresponds more and more to smaller particles: the epsilon coefficient increases from 1.14 to 1.21. The ARVI threshold is then an important parameter which drives the aerosol model.
Fig. 7. (Top) Histograms of the L2 aerosol product for the image corresponding to Fig. 5 for all DDV pixels, (Bottom) Same as top but only for DDV pixels whose ARVI is greater than nominal thresholds +0.07.

Fig. 8. Aerosol path reflectance over DDV pixels of Fig. 5 as a function of the ARVI, (left) 670 nm, (right) 443 nm.

This is explained by Fig. 8 where we plotted the retrieved aerosol path reflectance over DDV at two wavelengths where DDV is the darkest 670 and 443 nm. The chlorophyll absorption is higher in the blue compared to the red, the
reflectance in the blue remains quite constant when the ARVI decreases and thus there is no correlation between ARVI and aerosol path reflectance. Conversely, the vegetation reflectance increases in the red when the vegetation is less dense or less green (as ARVI decreases since ARVI is a good indicator of darkness). Therefore the increase of the aerosol path reflectance in the red is just a bias which should be corrected either in:

(i) Increasing the ARVI thresholds stored in the level 2 processor Look Up Tables. Of course, when you increase the ARVI threshold, you reduce the number of DDV pixels and the spatial coverage of the aerosol product.

(ii) Or applying a corrective method to be defined. Because the influence of the ARVI threshold on the aerosol product is understood, there is a possibility to do so. This alternative will allow proposing a reliable aerosol product with a better spatial coverage.

3.2 Sensitivity to the aerosol refractive index

The aerosol algorithm allows retrieving one size parameter (the slope of the Junge size distribution) and the number of particles (or the AOT). A third key optical parameter is the aerosol refractive index. At the beginning of the project, it was foreseen to get this parameter as an auxiliary data from aerosol climatology. This climatology does not exist and by default, the aerosol refractive index is set to 1.44 everywhere. It corresponds to a continental aerosol model. We processed the same image with 1.55 and results are shown in Fig. 9. Once again the tendency shown by this figure is representative of many other scenes.

The $\varepsilon$ factor is insensitive to this choice: 1.14 for $m=1.45$ and 1.13 $m=1.55$. For a given refractive index, the aerosol scattering functions is almost spectrally neutral. Then $\varepsilon$ simply corresponds to the spectral dependence of the measured aerosol path radiances irregardless of the aerosol refractive index. It is not the case for the OAT which varies from 0.15 if $m=1.44$ to 0.20 if $m=1.55$. The OAT retrieval depends upon the aerosol phase function which varies with the refractive index. Here for 1.55 (urban/industrial absorbing aerosol model) the phase function is generally lower than for 1.44 and thus the retrieved AOT is higher. The AOT distribution over that particular scene is broader for 1.55 than for 1.44 and this may indicate that this refractive index is not well adapted to this specific situation.

The need to have aerosol climatology still exists. This task can be achieved to some extend by ground based data such as collected in the AERONET network. The validation of the AOT, as reported in Fig. 6, may correspond to different assumptions on the refractive index $m$ in an in house software package. A more likely refractive index can be then proposed depending on time and location.

![Fig. 9. Same as top of Fig. 7 but for an aerosol refractive index set to 1.55](image-url)
4.  STATISTICAL ANALYSIS OF DDV COVER

As we have not yet covered all seasons with MERIS, we examined what we can expect in term of DDV area cover from SeaWIFS. We applied a MERIS like algorithm to SeaWiFS data and we focus here on the DDV flagging aspect.

4.1  A level 3 product for SeaWiFS

SeaWiFS (Sea-viewing Wide Field-of-view Sensor) provides data since the beginning of 1998 and exhibits good radiometric quality and data services. It has been chosen at the laboratory for the building of a medium spatial resolution, visible and near infrared image database. The data acquired correspond to the High Resolution Picture Transmission (HRPT) format that is direct SeaWiFS broadcast at full resolution (~ 1 km at nadir) over particular reception sites. Here Dundee University reception site was chosen as it runs without interruption since 1998 and covers most of Western Europe. Both widths and central wavelength of the bands are very similar and little adaptation of the atmospheric Look Up Tables (LUT’s) was necessary. The spatial resolution at nadir is of the same order if one takes High Resolution Picture Transmission (HRPT) data for SeaWIFS and reduced resolution L1B product for MERIS. The main difference is the geometry because SeaWiFS avoids sun glint (and therefore look in the hot spot direction above land) whereas MERIS does not. SeaWiFS input images are L1B images. They consist of 8 calibrated radiances, the sun zenith angle, the view zenith angle and the relative sun-view azimuth. The image is navigated and according to SeaWiFS team with an accuracy of ~1 pixel. Concerning the computational aspect, the algorithm is fully coded in IDL in order to be compliant with the SeaDAS software. It allows an easy comparison with the ocean product and makes visualising and saving results easy.

Tab. 1. DDV occurrence on 4 SeaWiFS high resolution images acquired in 2000 for different seasons (from the HRPT station of the University of Dundee). Cloud and DDV covers are calculated by averaging the result of the high resolution pixel classification over 16x16 pixels boxes. Then the DDV fraction is calculated by counting the number of super-pixel with DDV cover greater than a minimum value (here 2 %) and dividing by the number of land super-pixels. This calculation is done for cloud free, a maximum of 50% and 80 % of cloud cover for the super-pixels. For each image, DDV statistics are given for five ARVI thresholds starting from the nominal MERIS values and decreasing down to the nominal values minus 0.2.

<table>
<thead>
<tr>
<th>Image</th>
<th>Land super-pixel Number</th>
<th>Cloud free fraction</th>
<th>&lt;50% cloud cover fraction</th>
<th>&lt;80% cloud cover fraction</th>
<th>ARVI Thresh. decrease</th>
<th>&gt;2% DDV cover fraction (cloud free)</th>
<th>&gt;2% DDV cover fraction (&lt;50% cloud cover)</th>
<th>&gt;2% DDV cover fraction (&lt;80% cloud cover)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) S 2000 day: 051 11:22 UT</td>
<td>6364</td>
<td>0.347</td>
<td>0.547</td>
<td>0.663</td>
<td>0.00</td>
<td>0.000</td>
<td>0.003</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.05</td>
<td>0.000</td>
<td>0.005</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.10</td>
<td>0.000</td>
<td>0.007</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.15</td>
<td>0.001</td>
<td>0.014</td>
<td>0.033</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.20</td>
<td>0.009</td>
<td>0.035</td>
<td>0.064</td>
</tr>
<tr>
<td>(2) S 2000 day: 134 12:11 UT</td>
<td>8730</td>
<td>0.293</td>
<td>0.513</td>
<td>0.596</td>
<td>0.00</td>
<td>0.038</td>
<td>0.070</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.05</td>
<td>0.072</td>
<td>0.130</td>
<td>0.152</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.10</td>
<td>0.108</td>
<td>0.184</td>
<td>0.216</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.15</td>
<td>0.151</td>
<td>0.244</td>
<td>0.283</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.20</td>
<td>0.175</td>
<td>0.281</td>
<td>0.325</td>
</tr>
<tr>
<td>(3) S 2000 day: 225 12:33 UT</td>
<td>6886</td>
<td>0.239</td>
<td>0.503</td>
<td>0.619</td>
<td>0.00</td>
<td>0.043</td>
<td>0.083</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.05</td>
<td>0.038</td>
<td>0.110</td>
<td>0.142</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.10</td>
<td>0.054</td>
<td>0.157</td>
<td>0.202</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.15</td>
<td>0.067</td>
<td>0.194</td>
<td>0.254</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.20</td>
<td>0.080</td>
<td>0.224</td>
<td>0.297</td>
</tr>
<tr>
<td>(4) S 2000 day: 316 12:44 UT</td>
<td>4762</td>
<td>0.247</td>
<td>0.520</td>
<td>0.644</td>
<td>0.00</td>
<td>0.000</td>
<td>0.001</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.05</td>
<td>0.000</td>
<td>0.003</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.10</td>
<td>0.001</td>
<td>0.008</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.15</td>
<td>0.007</td>
<td>0.026</td>
<td>0.041</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.20</td>
<td>0.023</td>
<td>0.060</td>
<td>0.085</td>
</tr>
</tbody>
</table>
4.2 Results

Among the 3 years of SeaWIFS data, we have chosen 4 images acquired during 2000 over Europe for different seasons. On Table 1 is summarised the analysis of the spatial and temporal variability of DDV cover. It is confirmed that, using nominal ARVI thresholds (ARVI threshold decrease =0) that have been computed for real dark vegetation and standard atmospheric condition, it is possible to detect significant DDV area in spring and summer. In the case of DDV observed in cloud free conditions, one can expect to get 4-5 % of DDV cover in average. If we accept also DDV zones which are embedded in a cloudy environment, then DDV cover reaches 10 %. This is quite acceptable and allows for example, to be confident on the potential aerosol scattering corrections that can be done to the Rayleigh corrected reflectance (the actual MERIS level 2 surface reflectance product). However, in autumn and winter there are very few DDV zones, at best 1% and in cloudy conditions. Things go better if the ARVI threshold is decreased a bit, but from what we know from Section 3, it is at the cost of an increase of the bias on the aerosol product.

5. CONCLUSION

The first quality checks on MERIS aerosol products appear quite reasonable in terms of spatial continuity and values are in the expected range. Some threshold effects appear on the aerosol type characterization through the epsilon coefficient. These effects can be simply reduced by adding more aerosol models (here, a better discretisation of the slope of the Junge size distribution).

Validation points are too few to really validate the products. An extensive validation exercise as to be conducted. An investigation on the refractive index should be included in this validation exercise because of the influence of m on the AOT.

The concept of the DDV detection with ARVI works quite well. First, it seems that ARVI thresholds needs to be adjusted as DDV disappears late fall in some regions. Second, it appears that the aerosol optical thickness increases with ARVI and that the epsilon factor decreases with ARVI (leading to an aerosol model with larger particles) are significantly sensitive to ARVI. So, even if DDV appears to be suitable for aerosol remote sensing, more as to be done than simply consider DDV reflectances as constant above an ARVI threshold.

ACKNOWLEDGMENTS

This work was essentially supported by the European Space Agency. Authors want to thank particularly NASA DAAC, the University of Dundee and Orbimage for providing the SeaWIFS data. We thank also Brockmann Consult for the efficient delivery of MERIS data as well as for the early access to the MERIS toolbox beta version. We thank PIs of AERONET instruments used in this report, B. Holben, G. Zibordi, and F. Cabot.

REFERENCES


