ABSTRACT

The Level 2 processor for MERIS includes several complex modules which generate more than 20 geophysical parameters, scientific flags and quality flags, which are included in the Level 2 products. The products are available in full, reduced and partly in low resolution. During the commissioning phase all parameters and all product types have been verified.

The first step of the processing is the pixel identification, i.e. the assignment of the correct surface type to a given pixel. This includes the cloud detection and the land/water reclassification. Both algorithms have been verified successfully. The cloud detection will be further improved in the future when additional tests become available.

Over cloud targets, the cloud albedo, optical thickness, top pressure and type are retrieved. All parameters are verified successfully after introducing a per pixel defined wavelength specification into the L1b product and the L2 processing.

Over land targets the gaseous absorption and Rayleigh scattering is corrected, and the MERIS global vegetation index and the bottom of atmosphere vegetation index are calculated. This atmospheric correction and the resulting surface reflectances and vegetation indices are verified successfully. The retrieval of the concentration of water constituents requires the identification of sun glint and, where possible, correction as well as a precise atmospheric correction. During the commissioning phase a detailed review of the these algorithms, and a fine tuning and dedicated improvement was performed. As a result, the water leaving reflectance spectra have been verified successfully for both, Case-1 and Case-2 waters. Only in complex waters, e.g. such with high absorption, the atmospheric correction needs further improvement. The finally retrieved algal pigment 1 and 2, total suspended matter, yellow substance and photosynthetically available radiation have been verified successfully.

1 INTRODUCTION

The Level 2 processor of the MERIS instrument is a complex software which includes several modules (the high level breakdown is shown in Figure 1) to generate the numerous geophysical parameters and flags which are included in the Level 2 products, e.g. such as surface reflectances, algal pigment index etc, or the surface classification flags or the confidence flags. The Commissioning Phase Plan Document (PO-PL-ACR-GS-001) has been compiled in preparation of the MERIS commissioning phase, which includes the definition of tests for all these modules and which takes interdependencies into account. A test is defined for a single algorithm – or a combination of them – leading to an information which contributes substantially to one or more Level 2 products. A test requires the processing and analysis of several MERIS scenes, and includes the tuning of thresholds and switches to optimise the performance of the algorithm and the quality of the retrieved parameters.
2 OBJECTIVES

The overall objective of the Level 2 processing verification is to ensure the nominal performance of the Level 2 processor. It is a prerequisite to start the scientific validation of the geophysical parameters. In this respect, a verification test is successfully passed when it has been proven that

1. the surface classification is correct
2. the algorithm generates products which values are in the expected range e.g. pigment index between 0.01 and 30 mg/m^3 or water vapour between 0 and 7 g/cm^2;
3. the algorithm yield values which are in accordance with common rules, e.g., higher pigment index at the coasts than in the Sargasso sea or higher water vapour in the tropics than above the Sahara (plausibility);
4. the algorithm generates images which have no visual artefacts, e.g. tiling, stripes, which were not detected in the Level 1b product;
5. the algorithm generates meaningful product confidence flags PCDs, i.e. flags which are raised in normally expected cases;
6. the formatting algorithm writes all products in the right place in the product file.

3 OVERVIEW OF THE TASKS

According to the MERIS L2 Commissioning Plan, the following tasks are covered by the Level 2 Verification:

- Pixel Identification Algorithm Verification
  The objective of this task is to verify the correct pixel classification, including cloud flagging and land reclassification:
  - Cloud screening
  - Land Identification
- Cloud Products Algorithm Verification
- Water Vapour Algorithm Verification
- Land Algorithms Verification
  - Bottom of Atmosphere Vegetation Index (BOAVI) and MERIS Global Vegetation Index (MGVI)
  - Land Atmospheric Correction (AC)
- Water Algorithms Verification
  - Water Confidence Checks
  - Turbid Water Screening and AC, Photosynthetically Available Radiation (PAR)
4 Detailed Results of L2 Verification

4.1 Pixel Identification/Cloud screening

These tests are dedicated to the cloud screening algorithms. A very important issue on these tests is to optimise the cloud screening through different sub-tests. Each of the parameters that have an impact on the cloud screening algorithm, has been tested independently first, because they all make use of different surface properties. After successful verification of each criterion, the contents of the decision table has been iterated in order to contain the optimal constellation of all parameters. The following figure illustrates the steps of the decision table optimisation:

The algorithm of the bright threshold test for the cloud screening is a simple comparison of the reflectance in the blue band located at 442.5nm with a threshold taken from an auxiliary database. If the reflectance exceeds the threshold value, the bright pixel flag is set. This flag might be used in a more complex classification scheme, the decision table.

At the time being the cloud detection is based solely on the bright test because the pressure products are not finally verified yet.

It was proven that the original bright threshold works best, but in combination with the slope and pressure tests, it has to be tested if an optimisation of the cloud detection can be achieved by lowering the bright threshold. A lower bright threshold is advisable in order to detect more cloud pixels. The subsequent tests will then refine the classification.

It has been tested, which influence the pixel with thin clouds or at cloud border have which are not classified as cloud pixels. Most of these pixels cause wrong values in the water products like Algal Pigment Index 1 or Total Suspended Matter. Therefore, more pixels should be classified as cloud pixels.
4.2 Pixel Identification: Land Identification

This task is dedicated to the land reclassification algorithms. The test is of special importance in intertidal areas because the shape of the coastline might change there. But it also includes the test on land-in-water (island) and the test on inland-water. At the very beginning of the land identification stands the computation of the uncertainty flag. This flag is retrieved by looking up the pixel coordinates in an auxiliary data file called the Surface Confidence Map. This map had been generated by declaring every pixel in a radius of 0.2° around the coastline (which is in 0.01° resolution) as “uncertain”. The effect is that pixels identified in that manner are submitted to a reclassification that bases on radiometry.

**Status**
- Uncertainty map and re-classification based on radiometry successfully verified
- Significant improvement compared with map-based L1b coastline, especially in tidal areas

Figure 4 and Figure 5 show that the L2 land mask is much more reliable than the L1b coastline mask, which is taken from a map with 0.1 ° resolution, while the L2 land mask bases on radiometric reclassification.

4.3 Cloud Products Algorithm

The objective of this test is to verify the correct cloud algorithms, including cloud top pressure (CTP), cloud optical thickness (COT), cloud albedo (CA) and cloud type (CT).
A first verification has been completed by comparing the consistency of COT and CA, which are both derived from MERIS band 10 (753nm) and by visual inspection of numerous MERIS images, whereby the COT, CTP and CA values have to be plausible.
Both CA and COT appear in their proper ranges and show reasonable values. Figure 6 shows the expected relation of high CA values related to high COT values and vice versa.
Figure 6: Scatter Plot of COT against CA

Figure 7: stripes in CTP product (old aux data)  
Figure 8: CTP product (new aux data)

Figure 9: Profile Plot of track shown in Figure 8
Figure 10: Scatter Plot of CTP computed with recent against former aux data

- Cloud Top Pressure (CTP):
Generally the CTP shows reasonable values and appears in the expected range. The profile plot in Figure 8 additionally shows the expected behaviour.
During CTP verification it was achieved that the strong transition borders between MERIS cameras disappeared after a update of the neural net which calculates the CTP. However, fine stripes in product resulting from the spectral shift remained; a new CTP neural net has been generated which takes into account the exact wavelengths of every pixel in an image. The MERIS L2 processor has been updated accordingly. With this update also the small scale variation disappears.

In respect to the highly variable nature of clouds, a more reliable test is founded on a longer-term statistic of MERIS cloud parameters. The evaluation is based on the comparison of MERIS monthly averaged values with large-scale monthly mean values retrieved by ISCCP. The CT parameter contained in the MERIS L2 product is coded with a simple indexing scheme, following the ISCCP coding conventions. This coding combines the CTP and the COT values to retrieve the CT index. The verification of the CT indexing algorithm cannot be done directly with the scheme described above, because there are no reference data available through the ISCCP. The verification of the CT parameter is done by applying the simple indexing algorithm to the ISCCP reference data and comparing it to the MERIS retrieved CT mean values. This long-term test has to be completed, because the available time series of cloud parameters, working with the updated processor for the CTP, is too short.

4.4 Water Vapour (WV) Algorithm

The Water Vapour generally appears in the proper range $[0…7]$ g/cm$^2$ and shows reasonable values. Special features are explained in the following.
Figure 12 shows the expected relation of high WV values over water and land surfaces (green to blue colour gradient) and to low values above cloud surfaces (orange to yellow colour gradient).
Figure 14 shows that the water vapour content over water surfaces has more or less the same size as over land. Also, the lesser discretisation of the values above water can be recognised, which is due to the 4*4 pixels WV computation (macro pixels).
Figure 16 shows two expected tendencies:
- the WV values above cloudy pixels are generally lower than over land
- the more the track (shown in Figure 15) progresses, the more mountainous areas are reached. This can be seen in the decreasing WV values in Figure 16.
Figure 11: Water Vapour Product for a scene located at the Amazon delta

Figure 12: Histogram for WV of the scene shown in Figure 11

Figure 13: Ocean-Land transition track

Figure 14: Profile Plot for track shown left.
4.5 Land Algorithms: BOAVI and MGVI, Land Atmospheric Correction

In Figure 17, which represents partly Iran and Turkmenistan, three areas with the following characteristics are marked:

(1): sandy desert,
(2): steppe,
(3): mature green land on the edge of the Caspian sea.

Figure 18 to Figure 20 show the spectra for the land pixels that are located in these significantly different areas:

Figure 18 shows the typical spectrum of the bare soil. The computed MGVI of 0.05 fits well.
Figure 19 shows an increase of reflectance starting around 700nm, which indicates the presence of some vegetation. The computed MGVI of 0.27 adds up.
Figure 20 finally shows a typical vegetation spectrum. The computed MGVI of 0.87 emphasizes the matter.

The L2 surface reflectance that is computed for land pixels is corrected for gaseous absorption and Rayleigh scattering, but not for aerosols. However, the above mentioned connections show that the L2 land algorithms yield reasonable results and are therefore implicitly verified all together.

The MAGVI has been extensively tested against the breadboard implementation with an excellent agreement.

The land surface pressure product suffers from the insufficient discretisation of the spectral shift. The processor update, which provides the exact wavelength for each pixel (see 4.3), improves the land surface pressure significantly. The final verification of this product has to be completed.
4.6 Water Algorithms: Water Confidence Checks

Figure 21, Figure 22, and Figure 23 show the benefit of the glint correction in the L2 Processor. In the uncorrected case, nearly half of the image (the eastern part) would be useless. After applied glint correction, only relatively small patches are masked. The last figure shows that a difference is visible only in medium glint flagged pixels (as expected) and that the main correction happened in the eastern part of the image. It should be noted that even with this correction, glint affected areas, i.e. those masked by the “medium glint flag” should be treated carefully, and those pixels which are masked as “uncorrectable glint” should be totally disregarded.
4.7 Water Algorithms: Turbid Water Screening, Atmospheric Correction, Photosynthetically Available Radiation

The detection of turbid water is a very important step in the Level 2 processing scheme. The atmospheric correction relies on the fact that the water leaving reflectance in the NIR bands is negligible, which is not true if the concentration of suspended matter is sufficiently high, so that the backscatter of these particles leads to a significant reflection in all bands, including the NIR ones. A special mode of the atmospheric correction is turned on in this case, which corrects this reflectance. A threshold of the top of atmosphere reflectance in band 560nm is used to trigger this mode. The threshold is computed for a given concentration of suspended sediment.

During the verification phase this threshold was optimised with respect to the quality of the retrieved water leaving reflectance and the water constituents. A value of TSM=0.75 g/m³ was found optimal.

With this setting of the turbid water detection threshold, reasonable water leaving reflectance can be generated both in clear and turbid waters, as shown in Figure 24. However, in some cases of complex water, the atmospheric correction needs more improvement. As an example, absorbing waters, such as the Baltic Sea with high concentration of Yellow Substance, are not treated correctly if the atmospheric correction finds absorbing aerosols. A temporary solution has been found through disabling absorbing aerosols in this case, but a general solution is still pending.

After correction of the scaling and offset values in the Level2 Configuration Auxiliary Product, the Photosynthetically Available Radiation appears in their proper ranges and show reasonable values (Figure 25)
4.8 Water Algorithms: Retrieval of Algal I and Case-II water constituents

Once the atmospheric correction has been stabilised, the retrieval of the water constituents in Case-I and Case-2 waters could be verified. It was found that the retrieved values are within the definition range of the algorithms, and that the general trends are correctly visible: low chlorophyll values are and negligible values of TSM and YS, are retrieved in the open ocean, whereby the TSM shows correlation with the chlorophyll, because TSM includes the backscatter caused by the inorganic parts of the phytoplankton. If approaching towards the coasts, the values for chlorophyll and TSM increase. The values for YS are generally low except very close to the coast and in the mouth of rivers. In this general trend also the agreement between algal pigment index 1 (which is valid only in Case-I waters) and algal pigment 2 (which is optimised for Case-2 waters) is reasonable, with a systematically slightly higher algal pigment 2. Figure 26 shows as an example of the values of the water constituent concentration is different parts (ROIs) of the Mediterranean and the Adriatic Sea.
Figure 25: PAR, showing angle dependent structure, values from 920 to 1630 myEinstein/m²

Figure 26: Water products in different water types
4.9 Product Formatting

It has been proven by inspection of the MPH, SPH and the other data sets, that the formatting of the MERIS Level 2 Reduced Resolution Product is correctly implemented; also recent IODD changes were implemented correctly.

The formatting of the MERIS L2 Full Resolution Product has also been verified successfully. This was confirmed with the comparison of a products where the FR data were down sampled to RR, with the corresponding RR product.

![Figure 27: FR Algal I product from IPF](image1) ![Figure 28: RR Algal I product from prototype](image2)

The above figures show a very good agreement between the FR product that was processed by the IPF and the RR which was processed with the prototype using the same auxiliary data.
The comparison of the difference “FR-RR Algal I” by down sampling brought the following results:
Mean difference: 0.011697 mg/m³
Standard deviation: 0.299058 mg/m³
Excluding differences > 2.0 mg/m³:
Mean difference: 0.012947 mg/m³
Standard deviation: 0.086581 mg/m³
Explanation: cloud border, coastline, unexplained (7 pixel)

The verification of the formatting of the MERIS L2 RRC and RRV products has to be preliminary verified successfully, while the formatting of the MERIS L2 Low Resolution Cloud Product (LRC) is only partly correct (Figure 29 - Figure 32):
- checks where RR was down sampled to LR were successful
- masking errors have to be fixed

5 CONCLUSIONS

The MERIS Level 2 processor is a very complex software, depending on a multitude of auxiliary data. During the ENVISAT CalVal phase all substantial modules of this software have been successfully verified, which includes all auxiliary data and the internal thresholds and switches, which were tuned to optimise the Level 2 products. A few geophysical parameter still need additional verification because the available time series of data does not permit a final quality assessment, yet.
The Level 2 products have already been given to the validation teams, and, on one side, the initial results of these teams confirm the successful verification, but they uncover also the need for additional tuning and improvements. This will be the tasks of the upcoming months.
The comparison of down sampled RR water vapour with the low resolution showed a good agreement.

Due to masking problems the COT and CTP of the LRC product the values may not be compared on a statistical basis.

6 ACKNOWLEDGEMENT

This work was conducted by the MERIS Level 2 verification team. Thanks is to all team members, the MAVT validation teams and ESA staff who all supported this activity with enthusiasm and persistence. Special thank is to Steven Delwart, Philippe Goryl, Ludovic Bourg, Christophe Ngo van Duc and Guido Levrini.