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1 Executive Summary

The SOW describes the activities to be carried out in the preparation and then validation of the MERIS 4th Reprocessing, aiming towards smooth transition towards Sentinel-3 products. This activity focuses on providing the support needed for algorithm upgrade and their validation by the MERIS Validation Team (MVT). While the ESL (Expert Support Laboratories) activities provide calibration, characterization, algorithm-implementation and testing, the MVT provides complementary support to algorithm changes, validation and protocols updates.

This activity therefore shall run complementary to ESL activities for the MERIS 4th Reprocessing. The tasks in this activity shall be linked to the activity of the ESL working group, the MERIS Quality Working Group (QWG), with each Partner dealings with different parts of the MERIS processing branches. The QWG define and discuss algorithm upgrades, in the first instance based on existing algorithms, which have been implemented in previous reprocessing (in the MERIS Ground Segment), or make proposals based on experience gained in related projects such as the Climate Change Initiative. Following implementation in the MERIS processor (MEGS/ODEA), and validated and tested against previous processing and other sensors; however, a key component of the validation process is comparison with in-situ data, usually stored within the MEris Matchup In-situ Database (MERMAID, http://hermes.acri.fr/mermaid/). ODESA (http://earth.eo.esa.int/odesa) is a complete Level 2 processing environment, working in parallel to MERMAID and comprising the source code of the ESA 3rd MERIS reprocessing for algorithm development. The software provides a MERMAID processing mode, offering bio-optical modellers an immediate validation of new algorithms against data of known quality and in a controlled configuration. These activities are conducted by both the QWG and MVT, and should be complementary to each other as algorithms are adjusted, tuned and re-implemented as needed.

The major outputs of this activity include a series of technical documents, including Algorithm Theoretical Basis Documents (ATBDs), validation reports and recommendations to the QWG, and in-situ radiometric and bio-optical measurements for inclusion in MERMAID.

2 Scope of the document

This document provides a summary of the MERIS-4RP validation and intercomparison with MERIS-3RP products as a deliverable of MS2 of the contract No: 1475.ACR-ARGANS.i1r0.PATP, which is an extension for ESA contract No.4000111320/14/I-LG “MERIS Validation and Algorithm 4th Reprocessing–MERIS Validation Team (MVT)”; hereafter named MVT. The main objective is to provide an assessment of the MERIS 4th Reprocessing products.

3 Validation approach and results

In this section we will present the validation activity per task.
3.1 Coastal Water and Baltic Seas (SU, TO and BO)

This task consists on:

1. Analysis of MERIS4RP vs in–situ dataset in Baltic Seas and Lake Vänern
2. Support to MERIS QWG for algorithm validation
3. On-going bio-optical characterization of Swedish water

MERIS4RP Level 2 (MEGS 9.6) reduced resolution data was ordered via ODESA facility, MERIS Online processing (http://www.odesa-info.eu/process_basic/basic.php) and provided by ACRI via ftp. The data was further processed in the SNAP software (Brockmann Consult GmbH, Germany).

The corresponding field data to the MERIS RR data was downloaded from the ESA MERMAID portal (http://mermaid.acri.fr). It consisted of two Case-2 water datasets: a) Swedish Baltic Sea coastal waters ‘NW Baltic Sea’ (derived from TACCS data measured by Stockholm University and normalized by ARGANS, UK, Figure 1) and; b) data from the Aeronet-OC station ‘Palgrunden’ in Lake Vänern (Figure 2).

![Figure 1. Field data from 16 match-up points from the NW Baltic Sea. Reflectance was measured with the TACCS radiometer at 7 wavelengths (412, 443, 490, 510, 560, 620, 665).](image-url)
Data analysis

The MERIS RR L2 data was extracted at 1x1 pixel size and checked for various flags for clouds (cc_cloud, cc_cloud_ambiguous, cc_cirrus) and glint (co_glint_risk).

From the radiometric data, the MERIS4RP reflectance products Mxx_rho_w (MERIS standard processor MEGS 9.6) and rho_wn_AAC_xx were further analysed and compared to the values measured in situ. rho_wn_AAC_xx is an output of the Neural Network processor which is a further development of the C2RCC processor that uses top-of-atmosphere radiances and applies an alternative atmospheric correction (AAC) (Brockmann et al. 2016).

For chlorophyll-a (chl-a), the MERIS4RP product CHL_NN, for total suspended matter the TSM_NN product, and for the absorption by CDOM (coloured dissolved organic matter) the ADG443_NN product were analysed. Note that CDOM absorption is usually dominant in the Baltic Sea, and we therefore use it as a proxy for ADG443.

In order to analyse the in situ data and MERIS4RP products differences, following statistics were calculated:

Root Mean Square Error in product’s units RMSE = \( \sqrt{\frac{1}{N} \sum_{i=1}^{N} (y_i - x_i)^2} \)

Root Mean Square Error in percentage pRMSE = \( \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left( \frac{y_i - x_i}{x_i} \right)^2} \times 100 \)

Mean Normalized Bias \( MNB = \frac{1}{N} \sum_{i=1}^{N} \frac{y_i - x_i}{x_i} \times 100 \)

Mean absolute error \( MAE = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{y_i - x_i}{x_i} \right| \times 100 \)

where \( x_i \) is the \( i \)-th in situ measurement, \( y_i \) is the \( i \)-th MERIS derived value, and \( N \) is the number of match-ups.
3.1.1 Mxx_rho_w product

After applying the cloud and glint flags, the standard product (Mxx_rho_w) over the NW Baltic Sea and Lake Vänern (Figure 3) shows two distinguished outliers and in general negative reflectance in the blue wavelengths (412.5, 442.5 nm). The two outliers are the coastal points from the NW Baltic Sea dataset (parameter land_dist_IS = 0) which passed the flagging criteria and were therefore included in the data analyses. These points were closest to the shore in the whole dataset. However, they were eliminated by the bright pixel atmospheric correction flag BPAC_ON (Figure 3, right). A large proportion of the reflectance values in the blue were negative, indicating slight atmospheric over-correction in this area.

![Figure 3. MERIS4RP Mxx_rho_w product over the NW Baltic Sea and Palgrunden before (left) and after (right) applying the flag BPAC_ON.](image)

From the AERONET-OC station Palgrunden, the distance to land is 5 km. In the NW Baltic Sea dataset, the distance to the land changes with the measurement station, typically along a transect towards the open sea. The distance to land is indicated through the colour code in the correlation plots below (Figure 4- Figure 8). Figure 4 shows the reflectance products from the standard MERIS algorithm (MERIS4RP), Mxx_rho_w against in situ data for every band before, and Figure 5 shows the results after applying the BPAC_ON flag. The statistics improve substantially after the removal of the 2 outliers.

The green band at 560 nm (M05_rho_w) shows the best agreement between the MERIS4RP radiometric and field data. The bands in the blue and blue-green (412.5, 442.5, 510 nm) show the most scattered results. In general, the Mxx_rho_w product show more accurate results for the green and red (560, 560, 620, 665 nm) bands. While the two coastal outliers are clearly visible in every band in Figure 4, the clear improvement of the results by applying the flag BPAC_ON is shown on Figure 5. The NIR channel (865 nm) here also consists mostly of noise (similar to 412 nm).

Both Figure 4 and Figure 5 demonstrate that the accuracy is clearly better for those match-up points that are further away from land, which indicates that, in general, coastal data should be corrected for adjacency effects from land.
Figure 4. MERIS4RP Mxx_rho_w product against in situ data in the NW Baltic Sea (round symbols) and at Palgrunden (triangle symbols). Standard processor, all pixels passing the cloud and glint flagging criteria.
The rho_wn_AAC_xx products show relatively good retrievals for all bands over these highly absorbing Case-2 waters although the higher scatter in the data seems also influenced by adjacency to the land. It shows that over inland water (triangles in Figure 7), the blue wavelengths are systematically overestimated - albeit only slightly - whereas there is an improved agreement for bands at 490 nm and 560 nm when compared to the Mxx_rho_w product. Again, applying the flag BPAC_ON (Figure 8) improves the retrievals by the rho_wn_AAC product. For the rho_wn_AAC products there were no values for the 12th and
the 13th bands (marked as NaN in the file), therefore the band at 865 nm could not be validated.

3.1.2 Alternative Atmospheric Correction outputs (rho_wn_AAC_xx product)

The accuracy between the radiometric field data and MERIS4RP products were highest in case of the rho_wn_AAC_xx products. Figure 6 shows the rho_wn_AAC_xx reflectance spectra for both datasets combined. There are no negative values in the reflectance spectra although the two coastal points have the lowest reflectance values over the whole spectra and differ clearly from the other spectra. The outliers, again, were eliminated by the BPAC_ON flag (Figure 6, on the right).

![Figure 6. rho_wn_AAC_xx product over NW Baltic Sea and Palgrunden before (left) and after (right) applying the flag BPAC_ON.](image)

The rho_wn_AAC_xx products show relatively good retrievals for all bands over these highly absorbing Case-2 waters although the higher scatter in the data seems also influenced by adjacency to the land. It shows that over inland water (triangles in Figure 7), the blue wavelengths are systematically overestimated- albeit only slightly - whereas there is an improved agreement for bands at 490 nm and 560 nm when compared to the Mxx_rho_w product. Again, applying the flag BPAC_ON (Figure 8) improves the retrievals by the rho_wn_AAC product. For the rho_wn_AAC products there were no values for the 12th and the 13th bands (marked as NaN in the file), therefore the band at 865 nm could not be validated.
Figure 7. MERIS4RP rho\_wn\_AAC product against in situ measured values in NW Baltic Sea (round symbols) and in Palgrunden (triangle symbols). Alternative neutral network (rho\_wn\_AAC\_xx product), all pixels passing the cloud and glint flagging criteria.
For both radiometric products, rho_wn_AAC and Mxx_rho_w, the statistics derived between MERIS4RP and field data is given in Table 1 below.

Table 1. The Root Mean Square Error (RMSE), Normalized Mean Bias (MNB) and number of match-ups (N) between MERIS4RP radiometric products and field measurements.

| rho_wn_AAC product after applying BPAC_ON flag |
| 412 | 443 | 490 | 510 | 560 | 620 | 665 | 865 |

Figure 8. MERIS4RP rho_wn_AAC product against in situ measured values in NW Baltic Sea (round symbols) and in Palgrunden (triangle symbols) after applying flag BPAC_ON.
### 3.1.3 Validation of chl-a, total suspended matter and absorption by CDOM products.

As the methods to derive the chl-a concentration from AERONET-OC data (Palgrunden, AERONET_chla_IS) and from field sampling (NW Baltic Sea, Spect_chla_IS) are very different, the data is analysed here separately. The MERIS4RP chl-a product for Case-2 waters (CHL_NN) shows very good agreement between in situ data and the satellite product ($R^2=0.7$) for the NW Baltic Sea dataset (Figure 9. CHL_NN product over over the NW Baltic Sea (round symbols, Spect_chla_IS) and Palgrunden (triangle symbols, AERONET_chla_IS). Figure 9), where chlorophyll was measured in situ.

The correlations is much lower for the Palgrunden data measured with AERONET-OC. Also, in the Palgrunden dataset, there was one value for chl-a 555.916748 µg/l (ID PAL_223_b_oc_PAL_2968_b_atm, date and time 20100526T103707Z), which was excluded from the analysis as it seemed completely out of range. It must also be noted that there are no in situ measurements of chl-a for the Aeronet-OC match-up reflectance data.

The chl-a data is retrieved from a bio-optical model that uses the reflectance data as an input and derives chlorophyll from that. This model seems not to perform very well for the highly absorbing waters (i.e. high CDOM absorption) of Lake Vänern, and it is therefore not really possible to test the chl-a product MERIS4RP with this data set (see Figure 9, right panel).
The total suspended matter product (TSM_NN, Figure 10, left panel) shows good correlation with field data but highly overestimates the values measured in situ, especially for higher concentrations; it seems to have a systematic error. The absorption by CDOM and detritus (Figure 10, right panel) shows clear underestimation compared to few field measured values.

The overall statistics for Chl-a, TSM and CDOM products are given in Table 2.

Table 2. The Root Mean Square Error (RMSE), Normalized Mean Bias (MNB) and number of match-ups (N) between MERIS4RP products and field measurements.

<table>
<thead>
<tr>
<th>Field data</th>
<th>SPECT_chla_IS</th>
<th>AERONET_chla_IS</th>
<th>TSM</th>
<th>CDOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>y = 0.7 x + 0.8, $R^2 = 0.72$</td>
<td>y = -0.1 x + 7, $R^2 = 0.028$</td>
<td>y = 3 x + 0.2, $R^2 = 0.71$</td>
<td>y = -0.2 x + 0.3, $R^2 = 0.00021$</td>
<td></td>
</tr>
</tbody>
</table>
3.1.4 Discussion

The results from this study demonstrate that for the Baltic Sea, the alternative neural net processor shows rather good results for reflectance retrieval, rho_wn_AAC. It has relatively low errors in the green to red part of the spectrum (MNB from -5 to 4 % for bands 510 to 665nm), with substantially increased errors in the blue (MNB about 363%). The reflectances derived by Mxx_rho_w were all negative (MNB from -21 to -6 % for bands 510 to 665nm), and the MNB values were substantially higher in 412 nm band (e.g. MNB in the blue us about -605%). But none of the processors really perform well in the blue part of the spectrum (Table 1, Figure 5 and Figure 8). A lot of the information in the blue channels seems to mostly consist of noise.

The alternative neural network also shows, as expected, much better results for chl-a in the highly absorbing waters of the Baltic Sea. The MERIS4RP chl-a product CHL_NN shows rather good agreement between in situ data and the satellite product (R2=0.7) for the NW Baltic Sea, and the RMSE was 0.88 mg m-3 (RMSE 48%) and the MNB was only 16%. This seems a clear improvement compared to the previous version of the MERIS processor, which had a MNB of about 55-62 % and a RMS error of about 80-90% (Beltrán-Abaunza et al., 2014) for FR data. It may be expected that the results for the MERIS4RP chl-a product CHL_NN improve even more when assessed on FR data. Previous work has shown that the use of FR data improves the retrieval results by about 50% when assessing the average of absolute percent difference, (apd) as presented in Kratzer et al. 2012, and the RMSE and the MNB also improved substantially.

Compared to the previous version of MERIS3RP (MEGS 8.4) the CDOM product of MERIS4RP (MEGS 9.1) seems to be slightly improved (it is closer to the real values), as it used to be underestimated by about ¼ of the real values, although it is still strongly underestimated. The MERIS (NN) estimated values for ADG443 shown in Figure 10 (right panel) are far too low as CDOM absorption alone is rarely below 0.3 m-1 in the open waters of the NW Baltic Sea. The slight improvement of the ADG443 product seems, in return, have affected the retrieval of the SPM product, which is now significantly overestimated, although there is a strong correlation with the data measured in situ. Previous research had shown that TSM derived from MEGS 8.4 used to be the most reliable product over the Baltic Sea with only a slight overestimation of about 10-15% (Beltrán-Abaunza et al., 2014) for FR data. The TSM product assessed here shows on overestimation of about 210% (MNB), and also a very high relative error (238 %), and thus can not be used as a reliable product in monitoring.
Furthermore, previous work in the NW Baltic Sea has also shown that the quality of the reflectance spectra in coastal pixels is improved when the data is corrected for adjacency effects using ICOL or SIMEC (Kratzer and Vinterhav, 2010; Kratzer et al., 2012, Sterckx et al. 2012 & 2015). In fact, ICOL led to a much higher number of match-ups for the NW Baltic Sea (Beltrán-Abaunza et al., 2014).

3.1.5 Conclusions and recommendations

The alternative neural network showed relatively good results for reflectance retrieval with low errors in the green to red, but higher errors in the blue-green and increasing a lot towards the blue. The standard algorithm underestimate the reflectance in all visible channels and had generally higher errors than the ACC and also had large errors in the blue, and in the red. The Case-1 algorithm OC4Me algorithm, as expected, does not work well for water product retrieval in the strongly absorbing waters of the Baltic Sea. The alternative NN approach (which is based on a further development of the C2RCC) and tested here on RR data in the NW Baltic Sea shows a strong improvement for the chl-a product retrieval, and a slight improvement for the ADG443 product, but a clear deterioration of the TSM product when compared to MERIS3RP (MEGS 8.4) data.

However, it is likely that the results will change significantly when FR data is used. Currently, it is not possible to compare these results directly to previous assessments of MERIS3RP (MEGS 8.4) data as there is no access to full resolution MERIS4RP (MEGS 9.6) data as yet. In order to perform a meaningful assessment, the validation teams need to get access to the reprocessed FR data, and all groups must work on exactly the same version of MEGS 9.6 data. Otherwise a comparison between regions will not be meaningful.

For the coastal zone an adjacency correction is also likely to improve the results, with an increased number of valid match-up data. If no adjacency correction is applied or available we recommended to use the bright pixel atmospheric correction flag (BPAC_ON) while using the MERIS4RP products over coastal and inland waters.

References


3.2 BIOMAP Neural Network Inversion Validation: Comparison of MERIS 3rd vs. 4th reprocessing (CIMA)

3.2.1 Overview

This report presents the results and discusses work performed by the Center for Marine and Environmental Research (CIMA) of the University of Algarve, PT, to compare MERIS 3rd vs. 4th data reprocessing results (M3RP and M4RP) within the framework of the contract No. ARG/003-025/1406/CIMA.

In agreement with ARGANS study specifications, the first requirement considered is the statistical validity of M3RP and M4RP results comparison. An extended list of MERIS remote sensing images has been selected for this purpose. The screening was undertaken based on the NASA OceanColor Web data archive [https://oceancolor.gsfc.nasa.gov/], duly acknowledged for the data disposal. The M3RP and M4RP images have been identified by the CIMA staff taking into account the temporal distribution and the variability of environmental conditions in the Atlantic off the coast of Portugal, the study area of this work. The MERIS scenes are detailed below.

3.2.2 Data and Method

3.2.2.1 M4RP data

1. ENV_ME_2_RRG____20080627T104825_20080627T104946_____________0081_069_452____ACR_R_NT____SEN3
2. ENV_ME_2_RRG____20081114T104820_20081114T104941_____________0081_073_452____ACR_R_NT____SEN3
3. ENV_ME_2_RRG____20090422T105110_20090422T105232_____________0081_078_223____ACR_R_NT____SEN3
4. ENV_ME_2_RRG____20090527T105112_20090527T105234_____________0081_079_223____ACR_R_NT____SEN3
5. ENV_ME_2_RRG____20090925T104817_20090925T104939_____________0081_082_452____ACR_R_NT____SEN3
6. ENV_ME_2_RRG____20091014T105104_20091014T105239_____________0095_083_223____ACR_R_NT____SEN3
7. ENV_ME_2_RRG____20100127T105106_20100127T105228_____________0081_086_223____ACR_R_NT____SEN3
8. ENV_ME_2_RRG____20100407T105105_20100407T105227_____________0081_088_223____ACR_R_NT____SEN3
9. ENV_ME_2_RRG____20100613T104521_20100613T104646_____________0084_090_180____ACR_R_NT____SEN3
10. ENV_ME_2_RRG____20100616T105103_20100616T105225_____________0081_090_223____ACR_R_NT____SEN3
3.2.2.2 Corresponding M3RP data

1. MER_RR__2PRACR20080627_102917_000026412069_00452_33071_0000.N1
2. MER_RR__2PRACR20081114_104222_000026332073_00452_35075_0000.N1
3. MER_RR__2PRACR20090422_103529_000026332078_00223_37351_0000.N1
4. MER_RR__2PRACR20090527_103249_000026432079_00223_37852_0000.N1
5. MER_RR__2PRACR20090925_103649_000026302082_00452_39584_0000.N1
6. MER_RR__2PRACR20091014_104200_000026332083_00223_39856_0000.N1
7. MER_RR__2PRACR20100127_104528_000026432090_00180_43320_0000.N1
8. MER_RR__2PRACR20100407_103201_000026432090_00223_43363_0000.N1
9. MER_RR__2PRACR20100613_102619_000026432090_00000_44093_0000.N1
10. MER_RR__2PRACR20100616_103201_000026432090_00223_43363_0000.N1
11. MER_RR__2PRACR20100806_103104_000026322091_00452_33071_0000.N1
12. MER_RR__2PRACR20100825_103551_000026292092_00223_44365_0000.N1
13. MER_RR__2PRACR20100929_104003_000026312093_00223_44866_0000.N1
14. MER_RR__2PRACR20110414_104708_000026233101_00267_47695_0000.N1

3.2.2.3 Quality flags

The following two cases of data products comparison are considered:

- 3RP Algal-1 vs. 4RP CHL_OC4ME
- 3RP Algal-2 vs. 4RP CHL_NN

The MERIS quality flags [1] applied to identify valid 3RP and 4RP pigment index values are detailed below:

- MERIS 4RP flags
  - For CHL_OC4ME: CO.DO_WATER and not (WP_PC.RHO_W_FAIL or WP_PC.CHL_OC4ME_FAIL
    or CC.CLOUD or CC.CLOUD_AMBIGUOUS or WP_QS_lsb.HAZE_OVER_WATER or
    WP_QS_lsb.HIGHGLINT or WP_QS_msb.ANNOT_ABSO_D or WP_QS_lsb.WHITE_SCATT)
  - For CHL_NN: CO.DO_WATER and not (WP_PC.CHL_NN_FAIL or CC.CLOUD or
    CC.CLOUD_AMBIGUOUS or WP_QS_lsb.HAZE_OVER_WATER or WP_QS_lsb.HIGHGLINT)
• MERIS 3RP flags
  – For Algal-1: l2_flags.WATER and not (invalid_algal_1 or l2_flags.CLOUD or l2_flags.HIGH_GLINT or l2_flags.ICE_HAZE or l2_flags.TOAVI_CSI or l2_flags.ABSOA_DUST or l2_flags.WHITE_SCATTERER or l2_flags.PCD_18 or l2_flags.CASE2_ANOM or l2_flags.CASE2_Y or (aero_opt_thick_865 > 0.6) or (wind_speed_modulus > 15))
  – For Algal-2: l2_flags.WATER and not (invalid_algal2_tsm_ys or l2_flags.CLOUD or l2_flags.PCD_17)

In addition, the following image pre-processing steps are applied:
• The WP_QS_lsb.HIGHGLINT mask in the 4RP products, as well as the l2_flags.CLOUD, l2_flags.HIGH_GLINT, l2_flags.ICE_HAZE and l2_flags.TOAVI_CSI masks are enlarged by 2 swath pixels [1] using an image filtering algorithm equivalent to the “Dilation 5x5” filter of the ESA SNAP Desktop program (version 5).
• The wind_speed_modulus is computed as ((zonal_wind)2 + (merid_wind)2)1/2.
• The pre-processed images are stored in the BEAM-DIMAP file format.

3.2.2.4 Pixel re-gridding

A prerequisite for direct comparisons of MERIS 3RP and 4RP products is the identical pixel geo-locations in paired images. Non-satisfiability of this work hypothesis is however documented when pairs of 3RP and corresponding 4RP images are considered. For example, Fig. 1 shows a set of pixel geo-locations taken from the paired MERIS images acquired on the 27th of June in 2008 in the Atlantic off Portugal, where blue crosses and red pluses indicate geo-locations (in longitude and latitude coordinates) of pixels from the 3RP and 4RP data, respectively. It is observed that 3RP and 4RP data points have different pixel geo-locations, even though the images have resulted from the same source of satellite observations. The geo-location differences appear systematic, but in reality there are no pixel-by-pixel, one-to-one correspondences between paired 3RP and 4RP images.

The solution considered in this comparison exercise to address the differences in pixel geolocations between 3RP and 4RP data relies on interpolation of a product value at a reference geolocation based on product values at 2-by-2 MERIS pixels surrounding the reference point (Figure 11). Specifically, the product value at the reference geolocation q is computed by bilinear interpolation of product values at the MERIS geo-located pixels p0, p1, p2 and p3 that form a quad containing the reference geo-location. Note that taking 4RP pixel geo-locations as reference and applying the re-gridding scheme to 3RP product values (or vice versa) could introduce a bias not easily quantifiable in the comparison results. For this reason, independent grid points are defined as reference, and the data interpolation is evenly applied (in a statistical sense) to both 3RP and 4RP product values. The reference geolocations identified to re-grid the 3RP and 4RP data are displaced on a Cartesian grid with uniform intervals of 0.01 degree in both longitude and latitude (see Figure 11).

Figure 11 shows a map of the Tagus estuary in the Lisbon area, where the red pluses indicate geo-locations (in longitude and latitude coordinates) of M4RP pixels, while the blue crosses show the pixel geo-locations of M3RP data points. Note that M4RP and M3RP data points
have different pixel geo-locations, even though the two images are derived from the same satellite raw data. It is also verified that, although the differences appear systematic, there is no pixel-by-pixel, one-to-one correspondence between paired 4RP and 3RP data. A common image registration method detailed next has then been adopted to avoid an artifactual biasing component in the comparison of data products.

Figure 11. (top) Different pixel geo-locations between a pair of M4RP and M3RP images in the case of the 25th of August in 2010. Red pluses indicate geo-locations of ROI pixels from the M4RP image, whereas blue crosses are those from the corresponding M3RP image; (bottom) Bilinear interpolation of a product value at a reference geo-location q based on product values at the geo-located pixels p₀, p₁, p₂ and p₃ forming a quad that contains the reference point q.

The solution implemented to minimize the effect of differences in pixel geo-locations of M4RP and M3RP data relies on the interpolation of product values at a reference grid-point utilizing the close-by values at 2-by-2 surrounding pixels of the original MERIS image (Figure 11).
Namely, the product value at the reference geo-location $q$ is computed by bilinear interpolation of product values at the MERIS geo-located pixels $p_0$, $p_1$, $p_2$, and $p_3$ that form a quad containing the $q$ point.

![Figure 12. Regions of interest (ROIs).](image)

It is noted that taking M4RP pixel geo-locations as reference and applying the re-gridding scheme to M3RP product values (or vice versa) could introduce a bias not easily quantifiable in the comparison results. For this reason, independent grid points are defined as reference, and the data interpolation is evenly applied (in a statistical sense) to both 4RP and 3RP product values. The reference geo-locations identified to re-grid both M3RP and M4RP data are displaced on a Cartesian grid with uniform intervals of 0.01 degree in both latitude and longitude.

### 3.2.2.5 Regions of interest

Sub-regional trends of differences between 3RP and 4RP pigment index values are investigated by considering valid pixels from selected regions of interest (ROIs) in

![Figure 14. These ROIs have been chosen to account for different environmental conditions that characterize coastal regions off Figueira da Foz, Lisbon, and Sagres (ROIs #1–3, respectively). Overall trends across the ROIs are also assessed by taking into account all valid pixels from the ROIs.](image)
### 3.2.2.6 Scatter plot statistics

For each pair of 3RP/4RP images and each comparison case of 3RP/4RP pigment index products, the agreement of 3RP product values $X_k$ with equivalent 4RP results $Y_k$ is quantified by scattering $\varepsilon_i^*$ and bias $\delta_i^*$ in percent defined as:

$$
\varepsilon_i^* = \frac{200}{N_i} \sum_{k=1}^{N_i} \frac{|y_k - x_k|}{y_k + x_k},
$$
$$
\delta_i^* = \frac{200}{N_i} \sum_{k=1}^{N_i} \frac{y_k - x_k}{y_k + x_k},
$$

where $N_i$ is the number of product values in the $i$-th MERIS image pair ($i = 1; : : : ; M$) and $k$ is product value index.

With $\zeta$ generically indicating $\varepsilon$ and $\delta$, overall statistical trends considering all the $M = 14$ pairs of MERIS 3RP and 4RP images are finally quantified by weighted mean $\mu$ and weighted standard deviation $\sigma$ of the statistical results $\{ \zeta_i \}$ as:

$$
\mu_\zeta = \frac{\sum_{i=1}^{M} p_i \zeta_i}{\sum_{i=1}^{M} p_i},
$$
$$
\sigma_\zeta = \sqrt{\frac{\sum_{i=1}^{M} p_i (\zeta_i - \mu_\zeta)^2}{\sum_{i=1}^{M} p_i}}.
$$

where $p_i$ are mixing coefficients here set to the proportions of the sample counts $N_i$ to the total number of samples $N_{tot}$ as follows:

$$
p_i = \frac{N_i}{N_{tot}},
$$
$$
N_{tot} = \sum_{i=1}^{M} N_i.
$$

### 3.2.3 Results

Product comparison results for each MERIS image acquisition date are presented below considering individual pairs of MERIS 3RP and 4RP images and taking the date (20100825) as example, product maps and scatter plot statistics are organized as follows:

- Maps of 3RP Algal-1 and 4RP CHL_OC4ME are presented in Figure 13.
- Color shades from red to blue indicate the density of data points from high to low.
- ROI statistics in the inset of scatter plots in Fig. 5 are detailed in Table 3, where $N_{tot}$ is the total number of ROI pixels regardless of product validity (see above) and $N_{val}$ is the number of valid ROI data.
- Comparison results between 3RP Algal-2 and 4RP CHL_NN products are analogously presented in Figure 15, Figure 16 and Table 4.
Overall trends of ROI scatter plot statistics are finally presented in Figure 17 and Figure 18.

Figure 13. Maps of pigment index values: 3RP Algal-1 (left) vs. 4RP CHL_OC4ME (right). in the Atlantic off Portugal on the 25th of August in 2010.

Recalling that this comparison example is performed over all the 14 dates and the results are reported in a separate report with more details.

Figure 14. Scatter plots of Chl-OC4ME vs. Algal-1 values interpolated by pixel re-gridding in ROIs #1–3, respectively in the Atlantic off Portugal on the 25th of August in 2010. Color gradients from red to blue indicate changes in the density of data points from high to low.
Table 3. Detail of the ROI-specific statistics shown as insets of Figure 14, as well as the overall agreement considering all ROI data.

<table>
<thead>
<tr>
<th>ROI</th>
<th>N_val</th>
<th>$\epsilon^\ast$ [%]</th>
<th>$\delta^\ast$ [%]</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1098</td>
<td>6.4</td>
<td>-4.5</td>
<td>0.96</td>
</tr>
<tr>
<td>#2</td>
<td>1269</td>
<td>6.2</td>
<td>4.6</td>
<td>0.97</td>
</tr>
<tr>
<td>#3</td>
<td>8008</td>
<td>5.7</td>
<td>3.6</td>
<td>0.97</td>
</tr>
<tr>
<td>Total</td>
<td>10375</td>
<td>5.8</td>
<td>2.9</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Figure 15. Maps of pigment index values: 3RP Algal-2 (left) vs. 4RP CHL_NN (right), in the Atlantic off Portugal on the 25th of August in 2010.
Figure 16. Scatter plots of Chl-NN vs. Algal-2 values interpolated by pixel re-gridding in ROIs #1–3, respectively in the Atlantic off Portugal on the 25th of August in 2010. Color gradients from red to blue indicate changes in the density of data points from high to low.

Table 4. Detail of the ROI-specific statistics shown as insets of Figure 16, as well as the overall agreement considering all ROI data.

<table>
<thead>
<tr>
<th>ROI</th>
<th>Nval</th>
<th>ε* [%]</th>
<th>δ* [%]</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>5493</td>
<td>16.4</td>
<td>-16.3</td>
<td>0.87</td>
</tr>
<tr>
<td>#2</td>
<td>9061</td>
<td>43.5</td>
<td>-43.0</td>
<td>0.93</td>
</tr>
<tr>
<td>#3</td>
<td>8028</td>
<td>30.9</td>
<td>-30.9</td>
<td>0.93</td>
</tr>
<tr>
<td>Total</td>
<td>22582</td>
<td>32.4</td>
<td>-32.2</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Figure 17. Overall (left) scattering and (right) bias trends plots of Chl-OC4ME vs. Algal-1 in ROIs #1–3, respectively.

Figure 18. Overall (left) scattering and (right) bias trends plots of Chl-NN vs. Algal-2 in ROIs #1–3, respectively.
3.2.4 Summary and concluding remarks

Results of direct comparisons between MERIS 3RP and 4RP pigment index values were presented in this report to quantify the effects of MERIS reprocessing revisions on end-user data products. Differences in pixel geo-locations between paired 3RP and 4RP images were documented, and a regridding scheme based on bilinear interpolation was proposed to enable the inter-comparisons of 3RP and 4RP results. The requirement on statistical validity of the analysis was addressed by taking 14 pairs of 3RP and 4RP scenes selected upon cloud-free regions of interest (ROIs) in the Atlantic off Portugues coasts. Highlights of image comparison results are summarized as follows:

- A modest bias was observed between 3RP Algal-1 and 4RP CHL_OC4ME pigment index values as shown by the mean $\mu_\delta^* = 2.2\%$ and standard deviation $\sigma_\delta^* = 7.5\%$. The overall positive bias implies that the 4RP version of the inversion scheme tends to give slightly larger values than the equivalent 3RP results.
- Comparisons between 3RP Algal-1 and 4RP CHL_OC4ME results also displayed different bias trends in a sub-regional scale, ranging from $\mu_\delta^* = -6.2\%$ in ROI #1 in the north (Figueira da Foz) to $\mu_\delta^* = 7.4\%$ in ROI #3 in the south (Sagres).
- Much larger differences were observed between 3RP Algal-2 and 4RP CHL_NN results as indicated by overall bias $\mu_\delta^* = -34.2\%$ and standard deviation $\sigma_\delta^* = 25.6\%$. Sub-regional differences in overall biases were only within a few percent points and significantly lower than those observed between 3RP Algal-1 and 4RP CHL_OC4ME.
- The documented statistical analysis shows that the changes in the MERIS reflectance products have limited effects on MERIS pigment index products for Case-1 waters, likely due to the fact the band-ratio inversion schemes concern only the slopes of input reflectance spectra.
- In contrast, the MERIS reprocessing revisions have more pronounced effects on the Case-2 pigment index products based on neural net (NN) schemes, most likely due to algorithm updates in terms of NN coefficients and also partly because the NN schemes take into account not only the slopes of input reflectance spectra but also the magnitude of spectral reflectance values.

3.2.5 References

3.3 MERIS4RP algal pigments validation over Portugal coastal water (Sagremarisco, FCUL and CIMA)

3.3.1 Overview
This report sets the basis for the validation of MERIS-4RP products of algal pigments planned under Task03: MERIS4RP algal pigments validation over Portugal coastal water of the MVT-CCN Project.

3.3.2 Objective:
To guarantee the consistency and comparability of data across the ocean colour missions undertaken by the European Space Agency (ESA), there is the need to validate and assess the impact of updated processing schemes on the final products distributed to end-users. Within the framework of MERIS Validation Team (MVT) activities, the 4th reprocessing of MERIS data was here assessed by comparing the algal pigment products with pigment data collected off the coast of Portugal during the MERIS mission (i.e. 2002-2012). This activity was a cooperation between Portuguese institutions (i.e. SagreMarisco Lda. (SGM), CIMA- UAlgarve, MARE-ULisbon) that gathered a quality controlled Chlorophyll-a (Chl) in situ dataset for the region, in order to assess the accuracy of satellite-derived Chl products and evaluate the impact of the 4th reprocessing on MERIS Chl products: i) the standard MERIS Algal Pigment Index 1 (MERAPI1) and ii) the MERIS Algal Pigment Index 2 (MERAPI2).

3.3.3 Pigment Databases:

3.3.3.1 SGM

a. Sampling area
Sagres along the southwest coast of the Iberian Peninsula (Figure 19) has been a validation site for ocean colour sensors since 2008. The locations of the in situ stations selected for validation measurements are at 2, 10, and 18 km offshore and at respective depths of 40, 100, and 160 m along a north to south transect (37° 00′34″N; 8° 54′07″W), perpendicular to the coast off Sagres (A, B, and C in the inset of Figure 19). At all the three station, radiometric measurements have been taken and water samples collected for subsequent filtration and pigment quantification at onshore laboratories.
Figure 19. (Upper panel) Geographic location of the sampling stations A, B and C (red, green and blue diamonds, respectively) off Sagres, SW Portugal, between 2008 and 2012; (middle panel) Map of sampling stations conducted between 2005-2008 (a); and between 2009-2011 (b) by MARE-ULisboa along and off the coast of Portugal; (lower panel) Location of matchups identified between the in situ pigment database compiled for the Portuguese coast and the MERIS 4th reprocessing dataset.

b. Method
SGM, in partnership with the University of Algarve, has been performing HPLC analysis of phytoplankton pigments since 2010, aiming mainly to characterize the local phytoplankton assemblages and to validate ocean colour remote sensing data. The analysis of the samples by HPLC follow the Scientific Committee Oceanic Research’s (SCOR) procedures described in Wright and Jeffrey (1997). The phytoplankton pigments retained on the filters were preserved in liquid nitrogen and extracted using 3–5mL of 90% acetone (for filters of 25 mm and 47 mm of diameter, respectively). Each filter was triturated with a glass rod followed by sonication for 20 seconds. After extraction for 4–6 hours, at 4°C, the triturated filters were sonicated for further 20s and centrifuged to clarify the filtrate. Aliquots of 1 ml from each extract were transferred to HPLC vials where water was added to each one to improve peak shape (Zapata and Garrido, 1991) (0.3 ml of water were manually added to each aliquot of 1 ml) before the diluted extracts were injected into the HPLC. The injection volume was 50μl, with a flow rate of 1ml.min⁻¹ and an elution program of 30 min. The Diode Array Detector (DAD) was configured at 436 and 450 nm, to detect and identify chlorophylls and carotenoids, respectively. Standards for quantification were acquired from DHI® Labs.

3.3.3.2 MARE-ULisboa

**c. Sampling area**

MARE-ULisboa pigment database is mostly focused on the north west coast of Portugal (Figure 19), including also a few data from the southern coast, the Gorringe bank region and the Moroccan coast. The pigment archive has been based on field activities of monitoring programs and several opportunity cruises (Table 5). The in situ data considered in this study were acquired from 2005 to 2012, mostly from early-spring to late-summer months. During this period, a band of higher Chl-a values along the north west coast can be commonly observed due to upwelling events set by the northerly winds (Fiúza, Macedo, & Guerreiro, 1982), with a marked cross-shelf gradient characterizing the separation from oceanic waters (Relvas et al., 2007). The variations in coastline and topography can contribute to specific circulation patterns that affect the variability of phytoplankton biomass found in the different sampling areas. The riverine input along the coast can also be a relevant source of nutrients for the phytoplankton growth. The database includes sampling in the Lisbon bay area, just outside the mouth of river Tagus.

*Table 5. List of oceanographic cruises and monitoring stations with respective sampling period, location, number of surface samples collected and retrieved Chlorophyll a (Chl a) concentration range (adapted from Sá et al. 2015).*
d. Method

During the sampling campaigns, surface water samples were collected and filtered through Whatman GF/F filters (nominal pore size 0.7 \( \mu \)m). Filters were immediately frozen and stored at \(-80\) °C until laboratory analysis with High-Performance Liquid Chromatography (HPLC) for pigment identification and quantification. For samples prior to 2009 (Figure 19), phytoplankton pigments were extracted with 95% cold-buffered methanol (2% ammonium acetate), sonicated for 1 min (Bransonic, model 1210, Hz: 47), left for 30 min at \(-20\) °C in the dark, and finally centrifuged at 1100 g for 15 min at 4 °C. The samples from later cruises were extracted with 95% cold-buffered methanol (2% ammonium acetate) enriched with trans-beta-apo-8'-carotenal (i.e., internal standard) for 1 h at \(-20\) °C in the dark. At half-time period of extraction, samples were sonicated for 5 min, and after extraction centrifuged for 5 min. All extracts were filtered (Fluoropore PTFE filter membranes, 0.2 \( \mu \)m pore size) and immediately injected in the HPLC. Pigment extracts were analyzed using a Shimadzu HPLC comprising a solvent delivery module (LC-10ADVP) with a system controller (SCL-10AVP), a photodiode array (SPD-M10ADVP), and a fluorescence detector (RF-10AXL). For samples prior to 2009, chromatographic separation was carried out using a C18 column for reverse phase chromatography (Supelcosil; 25 cm long; 4.6 mm in diameter; 5 mm particles) and a 35 min elution program. The solvent gradient followed Kraay et al. (1992) adapted by Brotas and Plante-Cuny (1996) with a flow rate of 0.6 mL min\(^{-1}\) and an injection volume of 100 \( \mu \)l. For later samples, chromatographic separation was carried out using a C8 column for reverse phase chromatography (Symmetry C8, 15 cm long, 4.6 mm in diameter, and 3.5 \( \mu \)m particle size) and a 40 min elution program. The solvent gradient following Zapata et al. (2000) with a flow rate of 1 ml min\(^{-1}\) and an injection volume of 100 \( \mu \)l. All pigments were
identified from both absorbance spectra and retention times and concentrations calculated from the signals in the photodiode array detector. The HPLC system was calibrated with pigment standards from DHI for both methods.

3.3.4 Summary of results of HPLC inter-comparison

Within WP300, an inter-comparison between the HPLC methods used by SGM and MARE-ULisboa was conducted to guarantee consistency and comparability of Chlorophyll α databases for validation of satellite products for the Portuguese coast. The focus of the inter-comparison analysis was the estimation of uncertainties in the determination of in situ phytoplankton pigments concentrations by the two laboratories, taking into account both method and extraction procedures. For that purpose, the design of the comparison included two different sets of samples: i) a set of mixed standard pigments, and ii) a set of natural samples collected in three locations along the Portuguese coast. Results for precision and accuracy assessment are detailed and discussed in Deliverable 4 of WP300. In general, some underestimation by MARE-ULisboa was observed for higher TChl α concentrations. Still, results were linearly correlated to SGM data, indicating that a correction factor may be applied if a merging of databases is considered (Figure 20).

![Figure 20. Linear correlation analysis for TChl α determined by SGM and MARE-ULisboa (FCUL).](image)

3.3.5 Identification of Match-ups:

Once the pigment database was compiled, analysis of contemporary satellite data was conducted for identification of matchups (i.e time- and spatially coincident in situ and satellite data).
Based on the coordinates of each sample, a 3 × 3 pixel matrices were extracted from the MERIS Level 2 Full Resolution (FR, i.e. 300 m pixel resolution). A matrix was only compared with in situ data provided there were five or more valid pixels. A matchup between satellite and in situ data was only accepted when:

(i) in situ measurements coincided with the MERIS overpass (within 3h of satellite overpass for the W coast samples, and for the south coast: ±30 minutes at Station A and within ±1.5 hours at Stations B and C.

(ii) there were clear sky conditions;

(iii) there were good sea conditions;

(iv) the MERIS 4th reprocessing satellite data were filtered for contaminated pixels considering the following flags: INVALID, LAND, CLOUD, CLOUD_AMBIGUOUS, CLOUD_MARGIN, SNOW_ICE, COSMETIC, SUSPECT, HISOLZEN, SATURATED, HIGHGLINT, WHITECAPS, AC_FAIL, OC4Me_FAIL, ANNOT_TAU_06, ANNOT_DROUT, ANNOT_MIXR1, ANNOT_ABSO_D, RWNEG_03, RWNEG_04, RWNEG_05, RWNEG_06, RWNEG_07, RWNEG_08.

Using these procedures, it was possible to evaluate the performance of the two MERIS 4th reprocessing Chl products: i) the standard MERIS Algal Pigment Index 1 (MERAPI1) and ii) the Algal Pigment Index 2 MERAPI2.

MERIS Level 2 Full Resolution was used and analysed with the SNAP version 7.0 and a total of 63 matchups were identified (Figure 19). As expected, most matchups (i.e 49) are located in the Southwest coast, where sampling efforts were specifically addressed for MERIS validation activities and sampling only took place during satellite overpasses.

The in situ algal pigments used for satellite comparison correspond to the total chlorophyll-a (TChl) concentration (i.e. monovinyl Chla + divinyl Chla + chlorophyllide a + phaeopigments) quantified by HPLC referred hereafter as TChl_{HPLC}^{REF}. SGM has also determined Chl concentration through phytoplankton absorption coefficient (i.e., equivalent to standard MERIS Algal Pigment Index 2 (MERAPI2) referred as TChl_{ABS}^{REF}.

The set of matchups identified vary from 0.07 mg.m$^{-3}$ up to ~6 mg.m$^{-3}$, Table 6 shows the in situ data for TChl_{HPLC}^{REF}, TChl_{ABS}^{REF} for all the matchups, with respective metadata and MERIS 4th reprocessing derived data.

### Table 6. Algal pigments (TChl_{HPLC}^{REF} and TChl_{ABS}^{REF}) collected by the sampling campaigns made by SGM and MARE-ULisboa between 2005 and 2012, that were considered matchups. Information is provided about geolocation, time, region and station name, and respective MERIS 4th reprocessing derived values obtained from standard MERIS Algal Pigment Index 1 (MERAPI1) and Pigment Index 2 MERAPI2.

<table>
<thead>
<tr>
<th>Date of the Matchup</th>
<th>Latitude (N)</th>
<th>Longitude (W)</th>
<th>Time (UTC)</th>
<th>Region</th>
<th>Area</th>
<th>TChl_{HPLC}^{REF} (mg.m$^{-3}$)</th>
<th>MERAPI1 (mg.m$^{-3}$)</th>
<th>TChl_{ABS}^{REF} (mg.m$^{-3}$)</th>
<th>MERAPI2 (mg.m$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/05/2005</td>
<td>39°33'00''</td>
<td>10°00'00''</td>
<td>09:10:00</td>
<td>Nazaré</td>
<td>W</td>
<td>0.107</td>
<td>0.28</td>
<td>-</td>
<td>0.14</td>
</tr>
<tr>
<td>31/08/2005</td>
<td>38°30'00''</td>
<td>08°27'18''</td>
<td>08:33:00</td>
<td>Lisbon bay</td>
<td>W</td>
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<td>0.48</td>
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<td>08°29'53''</td>
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<td>-</td>
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<td>-</td>
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<td>-</td>
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<tr>
<td>Date</td>
<td>Location</td>
<td>Time</td>
<td>Coordinates</td>
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<td>N2</td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
<td>C4</td>
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</tr>
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<td>-</td>
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<tr>
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<td>1.150</td>
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</tr>
<tr>
<td>04/10/2008</td>
<td>36°56'06''</td>
<td>11:32:54</td>
<td>Sagres</td>
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<td>1.42</td>
<td>0.574</td>
<td>0.36</td>
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<td>0.378</td>
<td>0.63</td>
<td>0.346</td>
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<td></td>
</tr>
<tr>
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<td>Sagres</td>
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<tr>
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<td>Sagres</td>
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<td>0.20</td>
<td>0.418</td>
<td>0.09</td>
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<tr>
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<td>10:37:17</td>
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<td>B</td>
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<td>1.38</td>
<td>0.937</td>
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</tr>
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<td>C</td>
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<td>1.06</td>
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<td>Sagres</td>
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<tr>
<td>22/04/2009</td>
<td>37°00'24''</td>
<td>10:02:16</td>
<td>Aveiro</td>
<td>W</td>
<td>0.461</td>
<td>1.02</td>
<td>0.40</td>
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<tr>
<td>22/04/2009</td>
<td>36°52'20''</td>
<td>11:06:46</td>
<td>Sagres</td>
<td>C</td>
<td>2.162</td>
<td>3.69</td>
<td>1.017</td>
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<td>Sagres</td>
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<td>8.26</td>
<td>0.168</td>
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<td>0.461</td>
<td>1.02</td>
<td>0.40</td>
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<td>0.95</td>
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<td>36°55'51''</td>
<td>10:32:02</td>
<td>Sagres</td>
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<td>0.55</td>
<td>0.263</td>
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<td>0.25</td>
<td>0.167</td>
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<td>Sagres</td>
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<td>0.312</td>
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<td>Sagres</td>
<td>C</td>
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<td>0.38</td>
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<td>Sagres</td>
<td>C</td>
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<td>0.45</td>
<td>0.065</td>
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<tr>
<td>17/05/2011</td>
<td>38°40'59''</td>
<td>13:35:00</td>
<td>Cascais</td>
<td>W</td>
<td>0.974</td>
<td>3.62</td>
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<tr>
<td>20/05/2011</td>
<td>37°03'21''</td>
<td>09:36:12</td>
<td>Sagres</td>
<td>A</td>
<td>0.000</td>
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<td>0.000</td>
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<td>Sagres</td>
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<td>0.93</td>
<td>1.081</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>18/08/2011</td>
<td>36°56'37''</td>
<td>10:09:09</td>
<td>Sagres</td>
<td>B</td>
<td>0.422</td>
<td>0.66</td>
<td>0.378</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>18/08/2011</td>
<td>36°53'21''</td>
<td>10:39:20</td>
<td>Sagres</td>
<td>C</td>
<td>0.584</td>
<td>0.68</td>
<td>0.544</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>
3.3.6 Results of the Match-ups analysis

3.3.6.1 Algal pigments with MERIS 3RP and MERIS 4RP

The identified matchups were used to assess the uncertainties associated to the satellite algal pigment products for the study area, by specifically comparing the MERAPI1 and MERAPI2 products with the equivalent in situ data. Data products were evaluated through the scattering and the bias as absolute (APD) and signed (RPD) biased percent differences. Additionally, linear correlation parameters were also computed ($r^2$).
Figure 21: Match-up results obtained using (upper panel) the standard MERIS algal index 1 and $\text{TChla}^{\text{REF}}_{\text{HPLC}}$ as reference and (lower panel) the standard MERIS algal index 2 and $\text{TChla}^{\text{REF}}_{\text{ABS}}$ with 3rd RP (left column) and 4th RP (right column). Colours indicate sampling region (i.e. Stations A, B, C in the SW coast and W coast).
Figure 22: Match-up results obtained using the standard MERIS algal index 1 with 4th reprocessing analysed per sampling region (i.e. Stations A, B, C in the SW coast and W coast)
Figure 23: Match-up results obtained using the standard MERIS algal index 2 with 4th reprocessing analysed per sampling region (i.e. Stations A, B, C in the SW coast and W coast)

From the evaluation of the MERIS 3RP and MERIS 4RP algal pigments one may observe:

- Overall better agreement of the in situ data with the satellite data from the 3rd reprocessing (for both Chl tested products) (Figure 21-Figure 23);
- $\text{MER}^{\text{API1}}$ provided better agreement with in situ data than $\text{MER}^{\text{API2}}$ (for both 3rd and 4th reprocessing) (Figure 21-Figure 23);
- Best agreement with $\text{MER}^{\text{API1}}$ for Station B in the SW coast of Portugal (Figure 22);
- W coast stations with better results with $\text{MER}^{\text{API2}}$ (Figure 23)
3.3.6.2 Water leaving reflectance’s for the MERIS 3RP and for the MERIS 4RP

We used MERMAID-L2 from the MERIS 4RP dataset provided by ACRI-ST for this validation “L2_MERMAID_Algrave_20161127_164643_MP9_MEGS_39_48” then the results are compared with those from MERIS 3RP over Sagres region (Figure 19).

First, the analysis of the MERIS-3RP with 3X3 pixels extraction from full resolution images vs the in-situ measurements at Sagres between 2008-2012 are summarised on Figure 24 and Table 7. The results from MERIS 4RP with 3X3 and 9X9 pixels extraction from reduced resolution images vs the in-situ measurements at Sagres between 2008-2012 are summarised on Figure 24, Table 8 and Table 9 respectively.

Both the MERIS-3RP and MERIS-4RP show better results in the offshore stations (Station B and C). The MERIS-3RP shows higher errors in the blue and NIR bands (Table 7) than the MERIS-4RP for these extreme bands (Table 8 and Table 9).

The coefficient of determination ($R^2$) for the 443, 490, 510 and 560 nm is lower in Figure 24 in comparison with Figure 24. This result is probably related to the higher number of matchups in MERIS-3RP using the full resolution product.

Due to the proximity to land the Station A shows higher scattering and bias in all the wavelengths in comparison with the other two stations. In Table 9 the overestimation of the NIR band with respect to the in situ data is mainly influenced by the data from Station A. However, in this same station, the MERIS 4th reprocessing shows an underestimation between 412 and 560 nm (Table 9) in opposition to the results in the same bands when the MERIS-3RP was used where these bands are overestimated (see Table 7).
Figure 24: Scatter plots of (upper panel) MERIS-3RP $\rho_w$ and in situ $\rho_w$ at 443 and 560 nm between 2008 and 2012. Using 3x3 Matchup extraction from FR product; (middle panel) MERIS-4RP $\rho_w$ and in situ $\rho_w$ at 443 and 560 nm between 2008 and 2010. Using 3x3 Matchup extraction from RR product; (lower panel) MERIS-4RP $\rho_w$ and in situ $\rho_w$ at 443 and 560 nm between 2008 and 2010. Using 9x9 Matchup extraction from RR product. (red) station A, (green) Station B and (blue) Station C.

Table 7: Matchup analysis evaluated through the absolute ($\epsilon^*$) and relative ($\delta^*$) percent differences for Stations A, B and C using the MERIS 3rd Reprocessing $\rho_w$ vs in situ $\rho_w$ between 412, 443, 490, 510, 560 and 665 nm. This analysis uses a 3x3 Matchup extraction.
Table 8: Matchup analysis evaluated through the absolute ($\varepsilon^*$) and signed ($\delta^*$) unbiased percent differences for Station B and C using the MERIS 4th Reprocessing $\rho_w$ and in situ $\rho_w$ between 412 and 778 nm. This analysis uses a 3x3 Matchup extraction.

<table>
<thead>
<tr>
<th>$\lambda$ (nm)</th>
<th>ALL</th>
<th>Station A</th>
<th>Station B</th>
<th>Station C</th>
</tr>
</thead>
<tbody>
<tr>
<td>412</td>
<td>-23.1</td>
<td>31.8</td>
<td>35.9</td>
<td>47</td>
</tr>
<tr>
<td>443</td>
<td>-16.4</td>
<td>23.5</td>
<td>20.7</td>
<td>31.4</td>
</tr>
<tr>
<td>490</td>
<td>-9.8</td>
<td>16</td>
<td>7.5</td>
<td>17.2</td>
</tr>
<tr>
<td>510</td>
<td>-11</td>
<td>16.9</td>
<td>4.9</td>
<td>16.1</td>
</tr>
<tr>
<td>560</td>
<td>-11.1</td>
<td>17.7</td>
<td>0.2</td>
<td>14.7</td>
</tr>
<tr>
<td>620</td>
<td>-39.8</td>
<td>51.8</td>
<td>-55.4</td>
<td>61.4</td>
</tr>
<tr>
<td>665</td>
<td>-41.6</td>
<td>47.5</td>
<td>-3.9</td>
<td>37</td>
</tr>
<tr>
<td>680</td>
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<tr>
<td>709</td>
<td>-78.1</td>
<td>89.6</td>
<td>-90</td>
<td>95.3</td>
</tr>
<tr>
<td>753</td>
<td>-81.7</td>
<td>43.1</td>
<td>-79.2</td>
<td>49.6</td>
</tr>
<tr>
<td>778</td>
<td>-86.3</td>
<td>52.4</td>
<td>-90.9</td>
<td>76</td>
</tr>
</tbody>
</table>

Table 9: Matchup analysis evaluated through the absolute ($\varepsilon^*$) and signed ($\delta^*$) unbiased percent differences for Stations A, B and C using the MERIS 4th Reprocessing $\rho_w$ and in situ $\rho_w$ between 412 and 778 nm. This analysis uses a 3x3 Matchup extraction.

<table>
<thead>
<tr>
<th>$\lambda$ (nm)</th>
<th>ALL</th>
<th>Station A</th>
<th>Station B</th>
<th>Station C</th>
</tr>
</thead>
<tbody>
<tr>
<td>412</td>
<td>-12.5</td>
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<td>-18.2</td>
<td>30.8</td>
</tr>
<tr>
<td>443</td>
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<td>29.9</td>
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<tr>
<td>490</td>
<td>-13</td>
<td>20</td>
<td>-18.7</td>
<td>22.6</td>
</tr>
<tr>
<td>510</td>
<td>-11</td>
<td>18.7</td>
<td>-16.2</td>
<td>20.2</td>
</tr>
<tr>
<td>560</td>
<td>-8.9</td>
<td>20.6</td>
<td>-12.3</td>
<td>19.1</td>
</tr>
<tr>
<td>620</td>
<td>-35.3</td>
<td>55.7</td>
<td>-42.2</td>
<td>68.5</td>
</tr>
<tr>
<td>665</td>
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<td>680</td>
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<td>709</td>
<td>44.2</td>
<td>111.1</td>
<td>54.1</td>
<td>143.4</td>
</tr>
<tr>
<td>753</td>
<td>-63.1</td>
<td>64.5</td>
<td>-72.2</td>
<td>74.5</td>
</tr>
<tr>
<td>778</td>
<td>-33.8</td>
<td>70.8</td>
<td>-47.4</td>
<td>66.7</td>
</tr>
</tbody>
</table>
3.3.7 References:


3.4 Validation of MERIS4RP MTCI-products with data flux-net from Nebraska. (Univ. of Southampton)

Four full-resolution (FR) scenes produced using both the 3RP and 4RP processing baselines were examined for validation and verification of the MTCI in the 4RP. These scenes were acquired over France, Italy, Spain and the United Kingdom, covering both temperate and mediterranean biomes (Table 10). Initial evaluation is based on an intercomparison of the 3RP and 4RP products.

<table>
<thead>
<tr>
<th>Location</th>
<th>3RP</th>
<th>4RP</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>MER_FRS_2PNACR20081223_101837_000002782075_00008_35633_0000.N1</td>
<td>ENV_ME_2_FRG__20081223T101837_20081223T102316_0278_075_008_008ACR_R_NT_.SEN3</td>
</tr>
<tr>
<td>Italy</td>
<td>MER_FRS_2PNACR20080626_093711_000002172069_00437_33056_0000.N1</td>
<td>ENV_ME_2_FRG__20080626T093711_20080626T094047_0216_069_437_008ACR_R_NT_.SEN3</td>
</tr>
<tr>
<td>Germany</td>
<td>MER_FRS_2PNACR20040526_092700_000001462027_00122_11699_0000.N1</td>
<td>ENV_ME_2_FRG__20040526T092700_20040526T092926_0146_027_122_008ACR_R_NT_.SEN3</td>
</tr>
<tr>
<td>Greece</td>
<td>MER_FRS_2PNACR20060722_085538_000001912049_00365_22964_0000.N1</td>
<td>ENV_ME_2_FRG__20060722T085538_20060722T085850_0191_049_365_008ACR_R_NT_.SEN3</td>
</tr>
<tr>
<td>Spain</td>
<td>MER_FRS_2PNACR20060722_103529_000001972049_00366_22965_0000.N1</td>
<td>ENV_ME_2_FRG__20060722T103529_20060722T103846_0197_049_366_008ACR_R_NT_.SEN3</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>MER_FRS_2PNACR20060718_095659_000002202049_00309_22908_0000.N1</td>
<td>ENV_ME_2_FRG__20060718T095659_20060718T110039_0219_049_309_008ACR_R_NT_.SEN3</td>
</tr>
</tbody>
</table>

3.4.1 MTCI Values

Between the 3RP and 4RP, MTCI values demonstrate highly consistent spatial patterns, with very few differences evident visually (Figure 25). The shape of the frequency
The distribution of MTCI values is similar in both the 3RP and 4RP, although differences in magnitude are observed in all the investigated scenes (Figure 26). This is the result of a greater number of valid pixels being present in the 4RP, presumably due to improvements in surface classification and cloud masking, in addition to the increased range limits. For example, 5,640,102 pixels are valid in the 4RP scene over the United Kingdom, as opposed to 5,435,284 in the 3RP scene. In absolute terms, the differences between MTCI values in the 3RP and 4RP are typically small (P5 = -0.01 to -0.02, P95 = 0.05 to 0.12) (Table 11). Over all investigated scenes, differences are biased towards a slight increase in MTCI values, demonstrated by a positive mean difference of between 0.02 and 0.05. These differences demonstrate a spatial dependency, which appears to be related to slight changes in the calibration models of each MERIS camera in the 4RP (vertical stripes in Figure 27), in addition to the impact of smile correction (red areas in Figure 27). Nevertheless, these changes are sufficiently small to include no evident cosmetic effects in the MTCI itself. The median of the difference ranges between 0.01 and 0.04, this corresponds to <1% of MTCI maximum value.

The minimum and maximum difference values of the Germany and Greece scenes are greater than those shown in the rest of the scenes (Table 11). A closer inspection was conducted on the Greece scene where this effect is more pronounced (Figure 28 and Figure 29). The examination revealed that difference values lower than -3 were located in the north of Africa and correspond to pixels flagged as glint in the 3RP (Figure 28). On the contrary, difference values greater than 5 were observed in a cropland area in the north of Greece where pixels were flagged as invalid_boa_veg in 3RP (Figure 29). In both cases, the issue seems to be resolved in the 4RP. Finally, the 5th and 95th percentiles for the Germany and Greece scenes are in agreement with the rest of the scenes analysed in his report (Table 11).
Figure 25: MTCI in the 3RP (left) and 4RP (right) scenes covering France, Italy, Spain, the United Kingdom, Germany and Greece (top to bottom).
Figure 26: Frequency distribution of MTCI values for the 3RP (left) and 4RP (right) over the France, Italy, Spain, the United Kingdom, Germany and Greece (top to bottom)

Table 11: Summary statistics relating to the absolute difference in MTCI values between the 3RP and 4RP for the France, Italy, Spain and United Kingdom scenes.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>France</th>
<th>Italy</th>
<th>Spain</th>
<th>United Kingdom</th>
<th>Germany</th>
<th>Greece</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference (4RP-3RP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.32</td>
<td>-0.49</td>
<td>-0.45</td>
<td>-1.07</td>
<td>-3.059</td>
<td>-4.24</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.68</td>
<td>0.43</td>
<td>0.79</td>
<td>0.94</td>
<td>6.4</td>
<td>6.49</td>
</tr>
<tr>
<td>Mean</td>
<td>0.02</td>
<td>0.02</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.024</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
<td>0.02</td>
<td>0.22</td>
<td>0.11</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>1.61</td>
<td>1.25</td>
<td>0.95</td>
<td>0.95</td>
<td>7.85</td>
<td>4.57</td>
</tr>
<tr>
<td>Median</td>
<td>0.02</td>
<td>0.02</td>
<td>0.04</td>
<td>0.02</td>
<td>0.017</td>
<td>0.01</td>
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<tr>
<td>5th percentile</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.020</td>
<td>-0.01</td>
</tr>
<tr>
<td>95th percentile</td>
<td>0.06</td>
<td>0.06</td>
<td>0.12</td>
<td>0.05</td>
<td>0.046</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Figure 27: Difference in MTCI (4RP-3RP) for the France, Italy, Spain, United Kingdom, Germany and Greece scenes.
Figure 28: The Greece scene shows minimum difference values lower than -3 on the coast of north Africa (A). Closer inspection reveals that glint correction over land pixels in 3RP causes unrealistic high MTCI values (B) and (C). The 4RP scene (D), does not have that issue and the MTCI values are in agreement with the surrounding pixels.

Figure 29: The Greece scene shows maximum difference values greater than 5 at a cropland area in the north of Greece (A). Closer inspection reveals that correction of pixels for invalid boa_veg causes low MTCI values in 3RP (B) and (C). The 4RP scene (D), does not have that issue and the MTCI values are in agreement with the surrounding pixels.

3.4.2 Direct Validation with in-situ Canopy Chlorophyll Content Data

In addition to the intercomparison exercise, in-situ canopy chlorophyll content (CCC) data collected in two previous campaigns were used to facilitate direct validation of the 3RP and 4RP products.
The first campaign took place in Southern England over an agricultural area between 11/07/2006 and 19/07/2006. The sampling strategy was based on 8 characterizing large, homogenous fields, containing beans, linseed, wheat, grass, oats and maize. 3 to 5 elementary sampling units (ESUs) were established in each field, within which 25 measurements of leaf area index (LAI) and leaf chlorophyll concentration (LCC) were made (each an average of 4 to 8 replicates). LAI was estimated using the LI-COR LAI-2000, whilst LCC was estimated using a Konica Minolta SPAD-502 chlorophyll meter. Within each ESU, CCC was determined as the product of LAI and LCC. Further details of in-situ data collection are provided by Dash et al. (2010). For direct validation of the 3RP and 4RP products, MERIS data acquired on 18/07/2006 were investigated (Table 12). Additional georectification (i.e. beyond that provided in the product itself) was not undertaken, in constrast to Dash et al. (2010). Where a MERIS pixel was wholly composed of a single canopy type, the average CCC value of the ESUs contained within it was calculated.

Table 12: FR scenes examined for direct validation of the MTCI in the 4RP.

<table>
<thead>
<tr>
<th>Location</th>
<th>3RP</th>
<th>4RP</th>
</tr>
</thead>
<tbody>
<tr>
<td>United</td>
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<td></td>
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<tr>
<td>Kingom</td>
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<td>09____ACR_R_NT____.SEN3</td>
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<td>ENV_ME_2_FRG___20090817T092720_200908</td>
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<td></td>
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<td>17T093802_________________0642_081_3</td>
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<td></td>
<td>00394_39025_0665.N1</td>
<td>94____ACR_R_NT____.SEN3</td>
</tr>
</tbody>
</table>

The second campaign took place in Southern Italy over an irrigated agricultural area between 23/08/2009 and 25/08/2009. 36 ESUs of 20 m x 20 m were established over the site, which is mainly comprised of forage crops (alfalfa, maize), fruit trees (plum, apricot, kiwi, peach) and vegetables (aubergine, pepper, artichoke). As in the first campaign, LAI and LCC were derived using the LAI-2000 and SPAD-502. Within each ESU, 18 LAI and 30 LCC measurements were made. Further details of in-situ data collection and provided by Vuolo et al. (2012). To upscale in-situ data, a high spatial resolution CCC reference map was produced from RapidEye data acquired on 17/08/2009, by look-up table (LUT) inversion of the coupled Leaf Optical Properties Spectra (PROSPECT) and Scattering by Arbitrarily Inclined Leaves (SAIL) radiative transfer models (RTMs). Further details on RTM parameterization are described by Vuolo et al. (2010). This reference map was then validated using the in-situ data (r = 0.87, RMSE = 0.39 g m-2). For direct validation of the 3RP and 4RP products, both MERIS data and the high spatial resolution CCC reference map were reprojected to the same coordinate system and aggregated to a common spatial resolution of 1 km. Only 1 km cells in with vegetation cover of > 80% were considered, following Vuolo et al. (2012). The investigated MERIS data were acquired on 17/08/2009 (Table 12).
Agreement between the MTCI and in-situ CCC was assessed in terms of the Pearson product moment correlation coefficient. In the case of both campaigns, the 4RP products demonstrate an increased correlation when compared to the corresponding 3RP products (Figure 30 and Figure 31).

![Figure 30: Comparison between CCC and the MTCI for the 3RP (left) and 4RP (right) in the case of the first campaign in Southern England](image1)

![Figure 31: Comparison between CCC and the MTCI for the 3RP (left) and 4RP (right) in the case of the second campaign in Southern Italy](image2)
3.4.3 References


3.5 Comparisons of MER3RP and MER4RP L2 products (ARGANS)

This task consists on an intercomparison of the water reflectance and chlorophyll from both MERIS 3RP “MEGS 8.4” and MERIS 4RP “MEGS 9.6” over the NW-Black Sea and NW-European Seas. It is a contribution of ARGANS to the MERIS’RP validation report too.

3.5.1 Comparison of water reflectance over Black Sea

An intercomparison of the water reflectance and chlorophyll from both MERIS 3RP “MEGS 8.4” and MERIS 4RP “MEGS 9.6” is carried out over the NW-Black Sea near Galata and Gloria stations (Figure 32) using the following products:

- MER_RR__2PTACR20070512_081345_000001582058_00064_27172_0000.N1
- ENV_ME_2_RRG____20070512T081345_20070512T081623_________________0157_058_064____ACR_R_NT____.SEN3

The rho_w spectrum from both products show almost the same shape and behaviour, with maxima at 490 and 560 nm (chlorophyll contribution), and, then a decrease and almost no signal in the IR range >750nm (Figure 33). We observe that MERIS 4RP products performs better in the short wavelength e.g. 412 nm, where the atmospheric over-correction has been clearly improved. In general, the results show higher water reflectance (5%-10%) in MERIS 4RP wrt MERIS 3RP particularly over the short wavelength (Figure 34 & Figure 38).
Figure 32: Chlorophyll-a (OC4ME) from MERIS-4RP of the Black sea showing the three ROIs (blue-pins) ROI-1, (red-pins) ROI-2 and (light-green-pins) ROI-3, as well the Pins location; The shaded area on the right part of the image indicates the Medium Glint Mask. MERIS acquisition is on 20070512.
Figure 33: Spectral plots for each pin of (top) reflectance from MERIS 3RP and (bottom) $M^*_{\text{rho, w}}$ from MERIS 4RP. Thick curves indicate the ROIs average over the valid pixels (see Figure 32).
3.5.2 Comparison of water reflectance over NW-European Seas

An intercomparison of the water reflectance from both MERIS 3RP “MEGS 8.4” and MERIS 4RP “MEGS 9.6” is carried out over the NW-European Seas near (Figure 35) using the following products:

MER_RR__2PTACR20080507_104518_000004482068_00223_32341_000.N1
ENV_ME_2_RRG____20080507T104518_20080507T105246______________0447_068_223____ACR_R_NT____.SEN3

The spectrum of both products show almost the same shape and behaviour for bands longer than 500 nm, but with clear higher reflectance values wrt to MERIS 3RP. Different behaviours could be observed in the blue spectral range (412-490 nm) where MERIS 4RP shows higher reflectance for band 412 than for band 443, which is not the case for MERIS 3RP (Figure 36). In general, the results show systematically higher water reflectance (10%-20%) in MERIS 4RP wrt MERIS 3RP, particularly for ROI#4 (Figure 37).
Figure 35: Chlorophyll-a (OC4ME) from MERIS-4RP of the NW-European Seas showing the three ROIs (blue-pins) ROI-1, (red-pins) ROI-2 and (light-green-pins) ROI-4, as well the Pins location; The shaded area on the right part of the image indicates the Medium Glint Mask. MERIS acquisition is on 20080507.
Figure 36: Spectral plots for each pin of (top) reflectance from MERIS 3RP and (bottom) $M^*_\text{Rho} \_w$ from MERIS 4RP. Thick curves indicate the ROIs average over the valid pixels (see figure above).
Figure 37: Scatterplot of M*_rho_w from MERIS 4P to water reflectance from MERIS 3RP from NW-European Sea averaged over the three ROIs (see Figure 35).
MERIS Validation and Algorithm 4th Reprocessing –
MERIS Validation Team (MVT)

Final REPORT

Reference: No: 1475.ACR-ARGANS.i1r0.PATP
Revision: 2.2
Date: 02/10/2019
Page: 70/76
3.5.3 Comparison of Algal Pigment Concentration 1 (CHL_OC4ME) over Black Sea and NW-European Seas

In order to assess the pigments behaviour in MERIS 4RP “MEGS 9.6” products, we compare them to that ones from MERIS 3RP “MEGS 8.4” products. As the data format changed following to SEN3-like format, the comparison was carried out on the Algal-1 from MERIS 3RP to CHL_OC4Me from MERIS 4RP products respectively.

Figure 39 shows the chlorophyll retrieved in case-1 waters from MERIS 3RP (Algal-1) and from MERIS 4RP (Chl_OC4Me) over the Black Sea and the NW-European Seas. Both products display almost the same patterns with high chlorophyll values near the coast, which decrease toward
the open ocean areas. MERIS 4RP product shows less invalid (no-data) pixels (e.g. NW-Black Sea area) than MERIS 3RP product, this decrease of pixels number could be attributed to the earned pixels with negative reflectance in MERIS 3RP. This observation is confirmed by the pigments histograms (Figure 40), where MERIS 4RP histograms show higher number of pixels associated to higher pigments concentration wrt to MERIS 3RP ones. One can draw the same conclusion from the statistical analysis over the different ROIs from both acquisitions (Table 13).

Figure 39: Black sea (left) and (right) NW-European Seas (upper row) Algal-1 from MERIS 3rd RP and (lower row) Chl-OC4Me from MERIS 4th RP showing the ROIs locations. The shaded area on the right part of the image indicates the Medium Glint Mask. MERIS acquisitions are on 20070512 and 20080507 respectively.
Figure 40: Histograms of Pigments (blue) algal-1 from MERIS 3rd RP and (orange) Chl-OC4ME from MERIS 4th RP from different regions in (left) Black sea and (right) NW-European seas (see Figure 39).

Table 13: Pigments (Algal-1 and Chl-OC4Me) from the MERIS-3RP and MERIS-4RP in mg/m³ over Black Sea and NW-European Seas for different ROIs shown in Figure 39.

<table>
<thead>
<tr>
<th>Area</th>
<th>ROI</th>
<th>Algal-1</th>
<th>N#</th>
<th>Chl-OC4Me</th>
<th>N#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Sea</td>
<td>ROI-1</td>
<td>2.876</td>
<td>7628</td>
<td>2.559</td>
<td>7639</td>
</tr>
<tr>
<td></td>
<td>ROI-2</td>
<td>0.511</td>
<td>13678</td>
<td>0.505</td>
<td>14552</td>
</tr>
<tr>
<td></td>
<td>ROI-3</td>
<td>0.983</td>
<td>10006</td>
<td>0.959</td>
<td>8624</td>
</tr>
<tr>
<td></td>
<td>ROI-4</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>NW-European Seas</td>
<td>ROI-1</td>
<td>0.762</td>
<td>6317</td>
<td>0.705</td>
<td>7130</td>
</tr>
<tr>
<td></td>
<td>ROI-2</td>
<td>2.550</td>
<td>1074</td>
<td>2.702</td>
<td>1490</td>
</tr>
<tr>
<td></td>
<td>ROI-3</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>ROI-4</td>
<td>0.660</td>
<td>1383</td>
<td>0.919</td>
<td>3279</td>
</tr>
</tbody>
</table>
3.6 Improvement of high-latitude/high air mass water leaving reflectance and aerosol over land (HyGeos)

We validate the improved marine reflectances by checking the auto-coherence of data retrieved at high latitude the same day for several air masses. This analysis is performed in June in the Arctic region, here in particular from 1 to 10th of June 2010.

For each wavelength, each pixel observed at least 2 times during the day is compared to the reference, i.e. the value of the marine reflectance for that day with the smallest air mass (that has to be < 3). We plot the differences with the references as a function of air mass and accumulate statistics for the period of interest. An example is given in Figure 41 for the 3rd and 4th reprocessing marine reflectance at 412 nm. The scattering of the results give an idea of the precision (reproducibility) of the marine reflectances, and the slopes give a sensitivity to air mass which in turn reveals potential biases.

Both are significantly reduced for the 4th reprocessing.

The slopes are given for several visible channels on Figure 42. Values for the blue channels still exhibit an air mass dependency but quite low. The improvement between 3rd and 4th is clear. In the next step we will redo this exercise with a reference algorithm (POLYMER) with Level 1 coming from 3RD and 4th reprocessing to decompose the improvement due to the new level 1 data and the improvement due to the new level 2 algorithm.
Figure 42: Slopes of the regression of the absolute differences between marine reflectances and reference values vs air mass. Slopes are given for several MERIS channels for both reprocessing.
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