

VALIDATION OF MERIS GEOPHYSICAL PRODUCTS IN OPEN OCEAN AND COASTAL WATERS IN THE SOUTHERN NORTH SEA AND WESTERN ENGLISH CHANNEL

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ABSTRACT

The absorption coefficient of phytoplankton, detrital material and coloured dissolved organic material and *Chl a* concentrations were collected during cruises in 2002 & 2003 under the framework of the European Research Contract The Regional Validation of MERIS chlorophyll products in North Sea coastal waters (REVAMP, EVG1-CT-2001-00049). Three campaigns were undertaken in coastal regions of the North Sea, four campaigns were conducted in open ocean waters of the Celtic Sea and a bi-weekly time series was collected off Plymouth Sound in the Western English Channel. A total of 27 coincident MERIS images were identified over 246 stations. This paper quantifies the differences between in-situ measurements of the absorption coefficient of yellow substance (*YS*), chlorophyll *a* (*Chl a*) and Total suspended material (*TSM*) and the corresponding Level 2 geophysical products derived from coincident MERIS images. The results show that *Chl a* was underestimated by a 20%, *YSBPA* was underestimated by 42% and *TSM* was overestimated by a 16%. These errors fall within the specifications of MERIS products.

INTRODUCTION

MERIS was launched on the ENVISAT platform in March 2002. The sensor was designed to provide ocean colour imagery of the open ocean and coastal zone at high spatial resolution (~300 m), using 15 programmable bands with a resolution of 1.8 nm and radiometric accuracy <2% error [1, 2]. The expected accuracy of Level 2 ocean colour products is 10% for surface reflectance, 30% for *Chla* and *TSM* and 50% for *YS*.

During the first year after launch, a calibration and validation plan was set up to progressively improve the accuracy of MERIS products. The results of these activities during 2002 were presented at the MAVT workshop in December 2002. The spectral accuracy was 0.2 nm with a resolution of 0.05nm. The radiometric accuracy of the instrument showed less than 2.5% deviation from reference values, which was greater at blue bands (412 and 442 nm) and varied from camera to camera (the most affected were cameras 2, 5 and 3) [3].

MERIS Level 2 products were validated using different strategies of sampling: time series stations [4, 5], underway measurements from ferry lines [6] and dedicated and opportunistic cruises [7, 8, 9 and 10]. Measurements of normalized water leaving radiances from MERIS in the Northern Adriatic showed an absolute difference of ~12% [4]. Along the Dutch coast the difference between the mean in situ spectrum and the MERIS reflectance was smaller than 0.005 for bands 1 to 5 and smaller than 0.001 for bands 6 to 11 [8]. MERIS *Chl a* (AP2) was overestimated by 50% in Dutch waters and TSM was overestimated by 25% [8]. In the Skagerrak and Kattegat for a single MERIS match up, with no product flags raised, the difference in AP2 was 15% and in TSM was 20%, however when more images were considered with product flags raised, the difference was 2 to 3 times greater [10]. Only one comparison was made between in situ and MERIS YS in Dutch waters where YS was underestimated by a factor of two [8]. It was difficult to extract statistically significant conclusions from the results presented in the workshop, as the results for the North Sea were based on a total of five reflectance match ups and three Level 2 MERIS product match ups. The results did however point out that atmospheric correction over glint areas and over complex waters needed to be revised and that the product confidence flags were very sensitive. During 2003, most of these calibration issues were addressed and a reprocessing of MERIS products was performed in August 2003.

In this paper, measurements of in situ *TSM*, *YS*, *BPA* and *Chl a* are compared with MERIS data reprocessed in 2003. The results are discussed in relation to quality control of MERIS data and the science flags raised.

METHODS

Sampling

Sampling was conducted in coastal waters in the Western English Channel (WEC) and Southern North Sea (SNS) during eight campaigns in 2002 and 2003, as well as at a time series station in WEC during 2003. A total of 246 stations were visited: 120 in the Celtic Sea, 53 in the Western English Channel and 73 in the Southern North Sea .

The water samples were collected from the surface in 10 l Niskin bottle on all cruises, except Belgica 2003/12 where some additional samples were taken from the non toxic supply. Samples were filtered immediately on board. Filters for the analysis of *particle absorption* and *Chl a* were stored in liquid nitrogen and *TSM* samples were kept in -60°C freezer. *YS* was spiked with NaN_3 to conserve the sample and was analysed within 3 wks of collection. All other samples were analysed within three months of collection. The samples collected at the time series station (L4) were filtered within 3 hours of collection. *YS* was analysed fresh and *TSM*, *Chl a* and *particle absorption* were stored in the same condition as on the cruises.

Bleached Particulate Absorption (BPA) and Phytoplankton Absorption (a_{pig})

The absorption coefficient of phytoplankton and detrital material was determined on a Perkin-Elmer Lambda 800 spectrophotometer retro fitted with a 60 mm spectralon coated

integrating sphere using the method of Tassan and Ferrari [11]. The instrument was auto zeroed with free entrance ports, using high-grade spectralon plates at the exit ports. Baseline flatness was at least ± 0.004 A units. The bleaching agent was 3.33% NaClO, (0.1% active chlorine). 5 ml of MilliQ was re-filtered through the bleached GFF filter to remove any residual NaClO [11]. Blank filters were also bleached and re-filtered using the same procedure. The disappearance of the peak at 675 nm in the bleached sample and the concave shape of the OD spectrum near to 440 nm were used as evidence of complete filter bleaching [11]. Care was taken to ensure that both sample and blank filters did not dry out since this adversely affects the optical density of the sample. For processing the data, the wavelength path length correction factor of Tassan & Ferrari [11] was used.

Coloured Dissolved Organic Material Absorption Coefficient (YS)

Glass ware was acid cleaned and pre fired at 450°C. Milli-Q water was filtered three times through pre-rinsed 0.2 μ m polycarbonate filters. The filtrate was collected in dark borosilicate glass bottles and used as blanks. Samples were prepared and stored as per Milli-Q and were allowed to warm to the same temperature as the blank. Baseline was monitored to a variance <0.0005A units. Samples were run in 10cm cuvettes in dual beam mode with no integrating sphere. An auto zero was performed from 350 to 800nm with a cuvette filled with MilliQ in the sample cell and nothing in the reference cell. The MilliQ was then discarded and the cuvette was rinsed three times with 5 to 10 ml of the next sample and the scan was repeated. A MilliQ scan was run between every three samples to check the stability of the instrument. The MilliQ spectrum was subtracted from the sample spectra. No scattering offset correction was performed. The spectral absorption coefficient of the coloured dissolved organic matter was calculated from the measured absorbance as follows:

$$a_{ys}(I) = 2.303 * \frac{A_{ys}(I)}{l} \quad (\text{Equation 1})$$

where a_{ys} is the measured absorbance (relative units) and l is the cuvette path length (m).

Total Suspended Matter (TSM)

For measurements of *TSM*, between 250-2000 ml of surface seawater was filtered under low vacuum onto pre-ashed and pre-washed 47-mm Whatman GF/F filters following EU-JRC protocols [12] with an improvement in the rinsing of the filters following REVAMP protocols [13]. Mean and standard deviation were calculated from three replicates. A blank filter was used for each sample to monitor the precision of the balance.

Chlorophyll a (Chl a) and phytoplankton pigment determination

For pigment analysis, between 200-2000 ml of seawater was filtered under low vacuum pressure onto 25-mm Whatman GF/F filters. Phytoplankton pigment content was determined by High-performance liquid chromatography (HPLC) following the methods of Barlow et al. [14].

Further details on the protocols used for the measurement of the *YS*, *TSM*, *Chl a* and *particle absorption* can be found in the REVAMP Protocols [13].

Quality Control of MERIS Images

The products of MERIS defined in the MAVT validation document [15] are *YSBPA* which is the sum of *in situ YS* and *BPA*, *TSM* which corresponds to *in situ TSM* concentration, *AP1* which is the sum of chlorophyll-a, divinyl-chlorophyll a, chlorophyll a' and pheopigment concentrations; *AP2* which is the chlorophyll a concentration only. The difference between *AP1* and *AP2* is about 2% in our samples.

The definition of a “perfect” match up MERIS image is described in the validation protocols [15] as “a sample collected 0.5h before or after the MERIS overpass in case 2 waters and 1h in case 1 waters”. The errors in MERIS products using match ups outside of this time window have also been considered [4, 5, 6, 7, 8, 9, & 10]. In addition to the time restriction between overpass and sampling, the quality of the product has to be monitored using quality flags. Both confidence and science flags are created by MERIS as part of the Level 2 products. Only confidence flags (or *pcd* flags) with “false” values should be used for validation purposes. The most critical flag is the *pcd 1_13* reflectance flag. The science flags can indicate physical conditions that may adversely affect the product. For example high sun glint, dust-like absorbing aerosol and continental absorbing aerosol trigger the science flags which disqualifies a pixel from the analysis.

In this paper we have split the MERIS images into two categories, based on the type of flag raised:

- Quality 0 (Q0) is the nearest pixel sampled within ± 0.5 h of MERIS overpass, with no *pcd 1_13* flag and no high sun glint, dust-like absorbing aerosol and continental absorbing aerosol science flags raised.
- Quality 1 (Q1) is the nearest pixel sampled within ± 0.5 h of MERIS overpass, with the *pcd 1_13* flag raised and no high sun glint, dust-like absorbing aerosol and continental absorbing aerosol science flags raised.

From data collected in 2003, 4 *Q0* match ups were obtained (one from North Sea and three from L4) and 3 *Q1* match ups were obtained all from L4.

RESULTS & DISCUSSION

In Situ Data

The *in situ* data values for *Q0* & *Q1* match ups are given in Table 1. Station MC16 located on the Belgian coast had the highest *TSM*, *YSBPA* and *Chl a* values. The samples at L4 had lower *Chl a* values which mirrored the temporal evolution of the spring bloom typical

Table 1. *Chl a*, *TSM* (\pm standard deviation of three replicates for one sample) and the absorption ratio of inherent optical properties of the water column (data is scaled to 1): phytoplankton absorption (*aphy*), yellow substance (*ays*) and bleached particulate absorption (*abp*) at 442 nm.

Station	Chl a (mgm^{-3})	TSM (gm^{-3})	<i>aphy</i> : atot	<i>ays</i> : atot	<i>abp</i> : atot
MC16 16-Jun	9.92	8.11 \pm 2.14	0.531	0.012	0.424
L4 02-Apr	3.00	0.44 \pm 0.14	0.965	0.000	0.035
L4 22-Apr	3.76	0.40 \pm 0.17			
L4 14-May	3.63	0.64 \pm 0.11	0.895	0.003	0.079
L4 02-Jun	1.93	0.91 \pm 0.66	0.786	0.005	0.131
L4 05-Jun	1.73	0.84 \pm 0.28	0.867	0.003	0.071
L4 12-Jun	1.10	0.37 \pm 0.03	0.783	0.002	0.146

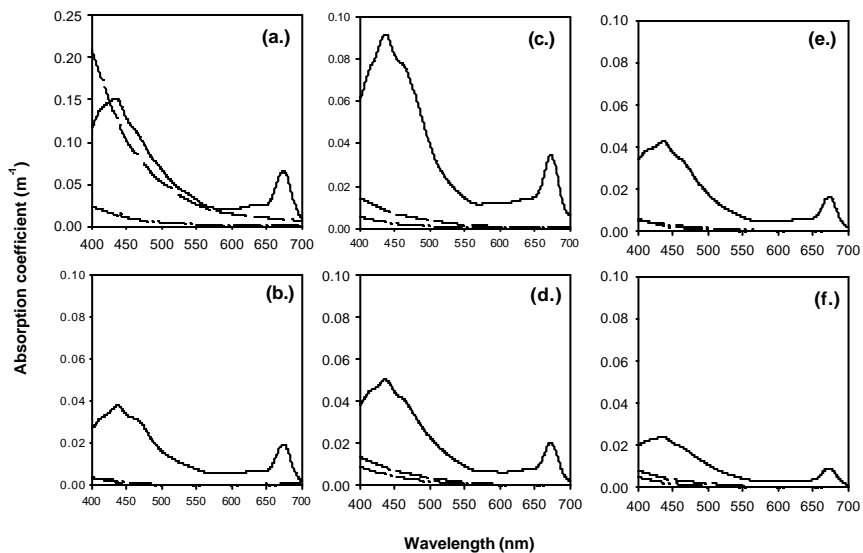


Fig 1. Absorption coefficient of phytoplankton (solid line), bleached particulate material (dashed line) & coloured dissolved organic material (dash dot line) for Station MC16 on the Belgian coast (a.) and Station L4 in Western English Channel on 02-Apr(b.), 14-May (c.), 02-Jun(d.), 05-Jun (e.) & 12-Jun (f.).

for this region. *TSM* concentrations at L4 varied by a factor of two and increased until early June which can be related to exceptionally dry and calm spring in 2003 followed by heavy rains and increased wind speeds in early summer. The relative contribution of *YS*, *BPA* and *aphy* to the total absorption is given in Fig 1 and the ratios at 442 nm in Table 1. The North Sea station was characterised by high *aphy* & *BPA* absorption and only 1% of the total absorption was due to *YS*.

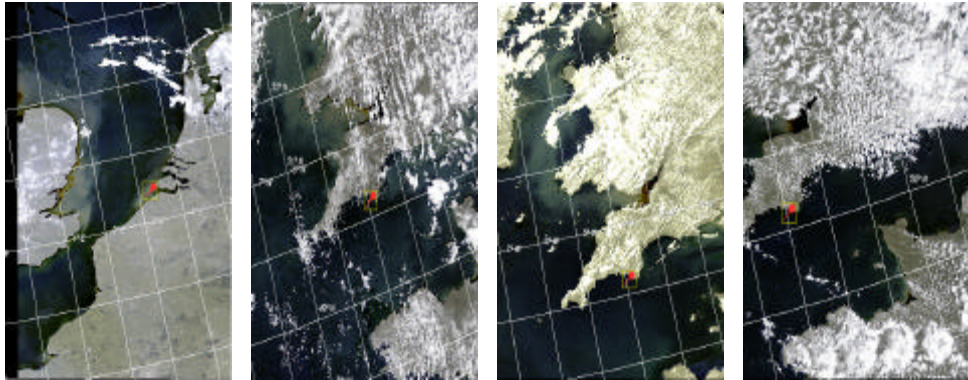
At L4 station, *aphy* dominated the total absorption (96% to 78%) which was greater than *BPA* (3.5% to 14%) and *YS* absorption was <1%. All the values measured for the *Chl a*, *YSBPA*, and *TSM*, are between the specifications of the neural net model used in the processor for the retrieval of MERIS level 2 products [17].

MERIS Level 2 Products

Table 2 summarises the product and science flags related to the pixels used for validation. Most of the pixels have the confidence flag raised for the case 2 products. The four *Q0* pixels don't have *rho_w* flags raised. One of them, station MC16 on Belgica 16, shows simultaneously valid flags for case 2 products (*AP2*, *YSBPA* and *TSM*). This pixel has a different atmospheric correction (C2S true) and an anomalous scattering (C2A true), that produces the invalidity of the product confidence flag for *API*.

Table 2. Flags recorded for the *Q0* (in italics) and *Q1* (normal font) match ups. The product confidence flags: *rho_w* reflectance, *API*, *AP2*, *YSBPA* and *TSM*. The product science flags are: CONT AER, continental absorbing aerosol; DUST AER, dust like absorbing aerosol; C2S, case 2 turbid water flag; C2A, case 2 anomalous scattering water; MEDGL, corrected for glint; HIGGL, high (uncorrected) glint. True flags indicate invalid product or science flag raised. Cam is camera number, from 5 to 1 eastward.

	<i>2-Apr L4</i>	<i>MC16</i>	<i>14- May L4</i>	<i>22- Apr L4</i>	2-Jun L4	5-Jun L4	12- Jun L4
<i>rho_w</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	T	T	T
<i>API</i>	<i>F</i>	T	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
<i>AP2</i>	T	<i>F</i>	T	T	T	T	T
<i>TSM_YSBPA</i>	T	<i>F</i>	T	T	T	T	T
CONT AER	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
DUST AER	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
C2S	<i>F</i>	T	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
C2A	<i>F</i>	T	<i>F</i>	<i>F</i>	<i>F</i>	T	<i>F</i>
C2Y	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
MEDGL	T	<i>F</i>	<i>F</i>	<i>F</i>	T	T	<i>F</i>
HIGL	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>	<i>F</i>
Cam	2	4	4	4	3	3	5



BE 16 Stn MC16

L4 02/04/2003

L4 22/04/2003

L4 14/05/2

Fig.2. RGB MERIS images for the rho_w valid match ups. Red dot indicates the sampling station.

Fig.2 shows the MERIS pseudo colour images of the four $Q0$ images. None of the images have the flags of atmospheric correction turned on, and only one (L4 – 02/04) had sun glint correction. Three of the images were taken from camera 4 and one from camera 2, therefore the $Q0$ images should be free from camera specific radiometric degradation. The $Q1$ images have reflectance and case 2 product confidence flags raised, while the $AP1$ is qualified as a valid value. Two of these were affected by medium glint (at L4 2nd and 5th of June) and one also had the C2A flag raised that did not produce an error flag for the $AP1$ product.

Comparison of *in situ* values with MERIS products is given in Fig 3. In general, MERIS underestimated $AP1$, $AP2$ and TSM , while $YSBPA$ was overestimated (Fig. 3). In terms of the confidence and science flags raised, the best image for the validation of MERIS products was MC16 and at this station $AP2$ was underestimated by 20%, TSM was overestimated by 16% and $YSBPA$ was underestimated by 42%. By comparison, at L4 with no confidence $Rh0_w$ flag raised, $AP2$ was under estimated by 43%, TSM was under estimated 35% and the difference in $YSBPA$ was 150% (Fig. 4). The higher accuracy at MC16 could be due the different atmospheric correction used at this station (as identified by the C2S flag; Table 2).

The errors in *in situ* measurements may have contributed to the differences at station MC16. Tilstone et al. [18, 19] found that the error in determining *in situ* measurements between laboratories was 22% for the YS and TSM , ~14% for the determination of $aphy$ and ~9% for $Chl a$. In general these differences are smaller than the differences observed between MERIS products and *in situ* measurements for station MC16 except for TSM which indicates that the gravimetric method could be improved.

The percentage difference between $Q0$ MERIS $Chl a$ and TSM products meets the initial specification (accuracy better than 30%, [2]) in two out of four pixels with no pcd

flags raised. The percentage difference between MERIS products and *in situ* measurements for the 2003 reprocessed data was similar to that obtained from the data processed in 2002, but for the 2003 data MERIS AP1 & TSM were consistently under estimated whereas for the 2002 data they were over estimated [8,10]. For the 2003 data, in all but one pixel YSBPA was over estimated and the difference was greater than the instrument specifications. For the Q0 images, this led to a disproportionate partitioning of total absorption between phytoplankton absorption and YSBPA absorption.

Even though the *in situ* samples are within the training range of the neural net algorithm used to derive AP2 [17, 20], almost all the images selected have the case 2 product flags. This was also identified during the 2002 data validation, but it seems that for the data reprocessed in 2003, the science flags still have a low triggering threshold.

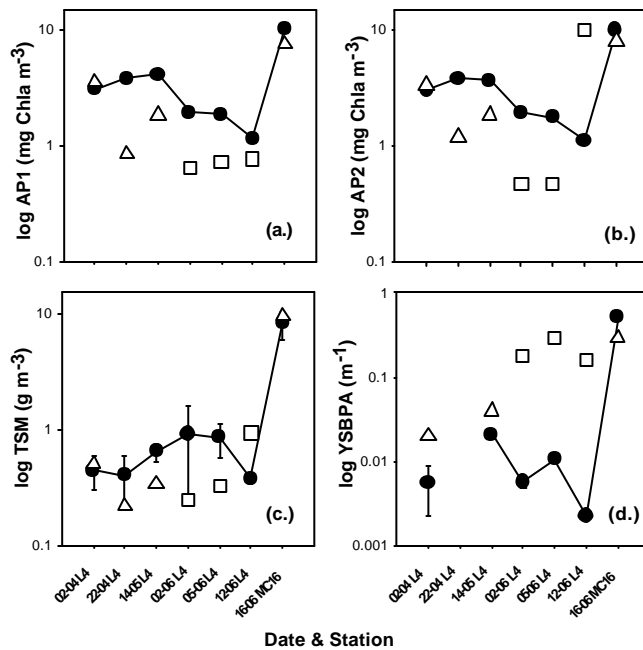


Fig 3. Validation of MERIS geophysical products with *in situ* data collected in 2003 (a.) Algal Pigment 1 - AP1, (b.) Algal Pigment 2 – AP2 (c.) total suspended material – TSM (d.) absorption of coloured dissolved organic material & bleached particulate material – YSBPA. Filled circles – *in situ* data; open triangles – MERIS quality 0 products; open squares – MERIS quality 1 products (for further information on quality product definitions see Methods). ± bars are standard deviations from replicate samples.

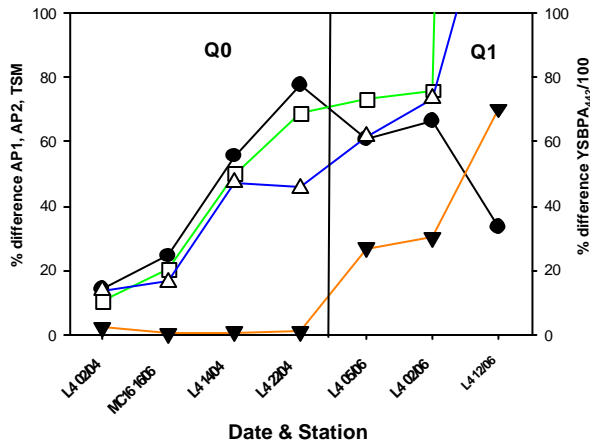


Fig 4. Percentage difference between in situ and MERIS AP1 (filled circles), AP2 (open squares), TSM (open triangles) & YSBPA (filled inverted triangles) at stations MC16 and L4 with no confidence flags (Q0) and with confidence flags (Q1) raised.

The image with the case 2 atmospheric correction flag gave the best results for all the parameters. However, when we compare Q0 and Q1 data (i.e. valid and invalid Rho_w flags), the errors in the case 2 products (AP2, YSBPA & TSM) were greater when the Rh0_w flag was raised compared to the error in AP1 (Fig. 4). AP1 therefore seems to be less sensitive to the Rh0_w flag. In addition, AP1 on the 5 June and 2 June had larger errors than on 12 June which corresponds with the triggering of the medium glint flag.

CONCLUSIONS AND RECOMMENDATIONS

- When no confidence flags were raised, MERIS underestimated *Chl a* by 20%, underestimated YSBPA by 42% and overestimated TSM by 16%. These errors fall within the specifications of MERIS products.
- AP2 performed better than AP1 in Q0 pixels, even if the flags for AP2 were raised.
- When the medium glint flag was raised, the results were good, suggesting that the atmospheric correction over glint areas has been improved since the last round of MERIS product validation.
- When the case 2 flag was raised the values obtained were within the specification limits, suggesting that the atmospheric correction over complex waters has been improved since the last round of MERIS product validation.
- The errors in MERIS case 2 products did not always correspond to the science flags raised, which suggests that the triggering of science flags could be improved.

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