

EARLY RESULTS FOR VALIDATION OF MERIS WATER PRODUCTS IN THE SKAGERRAK

Sørensen, K.,⁽¹⁾, Høkedal, J.⁽¹⁾, Aas, E.,⁽²⁾ Doerffer, R.,⁽³⁾ Dahl, E.⁽⁴⁾

- (1) Norwegian Institute for Water Research (NIVA), Brekkeveien 19, P.O.Box 173, Kjelsås, N-0411 Oslo, Norway. kai.sorensen@niva.no, jo.hoekedal@niva.no
- (2) University of Oslo (UIO), Department of Geophysics, P.O.Box 1022, Blindern, N-315 Oslo, Norway. eyvind.aas@geofysikk.uio.no
- (3) Institute for Coastal Research, GKSS Research Center, Geesthacht Max-Planck-Str., D-21502 Geesthacht. Roland.Doerffer@gkss.de
- (4) Institute for Marine Research, Biological Station Flødevigen, N-4817 Arendal, Norway. enar.dahl@imr.no

ABSTRACT

This paper describes the activities, methods and some preliminary results from the validation of MERIS Level 2 data in the Skagerrak during the summer 2002. The main data set is collected from the Skagerrak, but a few data are from the Kattegat and from the west coast of Denmark.

The objective of the study was to validate the MERIS data products for coastal water (CASE II), *i.e.* (i) to validate the MERIS L2 data products against *in situ* data from the area, and (ii) to validate the factors used in the conversion of neural network outputs, which are (1) the scattering coefficient by all particles in water, (2) the absorption by yellow substance and bleached particles (YSBPA) and (3) the absorption by phytoplankton pigments, to concentrations of (1) total suspended matter dry weight (TSM), (2) chlorophyll-a and (3) absorption by yellow substance at 440 nm.

A total of about 35 validation cruise days was performed in the period from May to September, and about 70 station have been investigated for optical properties and concentrations of chlorophyll-a, total suspended matter, yellow substance and bleached particle absorption. This paper summarises the methods involved and some preliminary results and conclusions.

The validation of the conversion factors showed that the conversion of the scattering coefficient of particles $b_p(440)$ to total suspended material (TSM) was in agreement with the MERIS protocol. The slopes of the bleached particle absorption are 20 % higher, but within the range of the standard deviation of slopes used in the MERIS reference model for training of the neural network output, which are based on data from the area around Helgoland.

For the conversion of the phytoplankton pigment absorption $a_{pig}(442)$ to the chlorophyll-a concentration (Chl2) the factor showed a value 3 times lower than in the MERIS reference model. The explanation for this is not yet fully understood. The slopes of the yellow substance (YS) are also in agreement with the data used in the reference model.

The validation is based on the MERIS Level 2 Reduced Resolution data available in November 2002, which consisted of 11 possible matchups. The available images have been investigated and statistics of the MERIS marine water leaving reflectance, the MERIS water products and the product and science flags have been extracted. These MERIS Level 2 data products have been compared to the corresponding *in situ* data. The preliminary results show that when the flag indicates that absorbing aerosol is absent the MERIS marine reflectance spectra show good agreement with the *in situ* data. However, there are many cases when at least one of the critical flags is on (sun glint, absorbing aerosol), which leads to significant deviations between MERIS and *in situ* measurements as well as to strange and unlikely water leaving radiance reflectances according to MERIS, indicating problems in the atmospheric correction.

1 INTRODUCTION

The Medium Resolution Imaging Spectrometer (MERIS) onboard ENVISAT was successfully launched on March 1st 2002. After a period of system testing and stabilisation MERIS has acquired

data also from the Nordic countries, except for a few periods of instrument switch-off. The validation activities in the Norwegian waters have been performed mainly in the Skagerrak with the addition of some field measurements in the Kattegat and off the west coast of Denmark. Other validation sites in Norway have been at the west coast of Norway co-ordinated by the Nansen Environmental Remote Sensing Center (NERSC). The optical *in situ* measurements and water analysis from these cruises have been performed by NIVA in a joint project with NERSC. The data from this area are not presented in this paper.

The objective of the measurements was to:

- compare *in situ* and *in vitro* determined optical quantities with the concentrations of chlorophyll-a, yellow substance, and total suspended material
- compare and validate the conversion factors between optical quantities and concentrations
- compare *in situ* water-leaving reflectances with MERIS reflectances
- quantitatively validate the MERIS Level 2 data products

The MERIS L2 products to be validated are:

- Water-leaving reflectance (r_w')
- Algae pigment index 2 (Chl2)
- Total suspended matter (TSM)
- Yellow substance (YSBPA)

One has to keep in mind that the MERIS Case 2 water products in fact are defined as optical properties, all at 440 nm, i.e. (1) the scattering coefficient for all particles, (2) the sum of the absorption by yellow substance and by the bleached particulate matter and (3) the absorption by phytoplankton pigments, which is the difference between the absorption by the total and the bleached particulate matter. The conversion into TSM dry weight is computed from the scattering component only, the conversion into chlorophyll-a from the pigment absorption only and the conversion to yellow substance absorption at 440 nm from the absorption by yellow substance and bleached particles.

2 THE TEST AREA

The Skagerrak differs from the rest of the North Sea by its wide range of depths, extending down to 725 m in the Norwegian Trench. The upper 50 meters is a vertically stratified surface layer, dominated by the surface currents, and the layer below is rather homogeneous, consisting mainly of Atlantic waters.

The Skagerrak and the Kattegat areas represent a transition zone between the North Sea and the Baltic Sea where three primary types of sea water mix [1]: (1) Baltic Sea water of low salinity (typically 8) and a high content of yellow substance, (2) North Sea water of Atlantic origin with salinity 35.0 or higher and a very low content of yellow substance, and (3) German Bight waters with a rather high salinity (typically 31) and a high content of yellow substance.

The Baltic Current transports an average freshwater supply of $15 \times 10^3 \text{ m}^3 \text{ s}^{-1}$ from the Baltic Sea [2], and during its course along the northern coast of the Skagerrak as the Norwegian Coastal Current it receives an additional $2-3 \times 10^3 \text{ m}^3 \text{ s}^{-1}$ of freshwater from the river run-off [3]. The total transport of the Norwegian Coastal Current is in the range $0.5-1 \times 10^6 \text{ m}^3 \text{ s}^{-1}$ [4-6]. The Atlantic North Sea water does not enter the area as a regular surface current, but its contribution to the central part and the deeper layers of the Skagerrak is crucial for the hydrographical and optical properties of the region. The Jutland Current carries waters from the German Bight into the Skagerrak, but its transport is generally assumed to be very variable and of an order of magnitude less than the transport of the Norwegian Coastal Current. It has been observed [7] that the local river run-off to the Norwegian Coastal Current occasionally may create local areas with a higher content of yellow substance than expected from their salinities. A lot of studies of the remote sensing and marine-optical properties of the area have been presented earlier [8-18].

The principal objective of this investigation has been to obtain representative observations from the mentioned different water types. Most of the field measurements were taken in the northern part of the Skagerrak (Norwegian Coastal Current and Atlantic North Sea water, 55 stations), but additional measurements have also been taken in the Kattegat (Baltic Sea water, 5 stations), on the Danish West

Coast (Jutland Current with German Bight water, 6 stations), as well as a few stations off the Norwegian West Coast in collaboration with NERSC.

The observed range for the underwater reflectance L_u/E_d at 510 nm was typically 0.002-0.012, for the content of chlorophyll *a* the range was 0,4 – 3,8 mg m⁻³ and for TSM 0,1 – 6,4 g m⁻³. The absorption by yellow substance at 443 nm in the open areas of Skagerrak is in average 0.3-0.4 m⁻¹ rising to about 3 closer to the coast.

The field campaigns were performed in the period from May 7 to September 18, with the sun zenith angle smaller than 60°, which is one of the criteria in the MAVT protocols [19]. Fig. 1 shows the test area and the location of the stations.



Fig. 1. Map of Skagerrak, Kattegat and the west coast of Denmark with the location of the validation stations in May to September 2002.

2 VALIDATION METHODS

2.1 Water-leaving reflectance, r'_w

To calculate the so-called water-leaving reflectance r'_w , which is the water leaving radiance (L_w) divided by the downwelling irradiance above surface (E_d), measurements of radiance from nadir in water L_u and downward irradiance in air E_d^{deck} were used. L_u was measured with a PRR-600 instrument from Biospherical Instruments Inc. and E_d^{deck} with a PRR-610 (from the same manufacturer). The instruments measure at the wavelengths 412, 443, 490, 510, 555, 625 and 665 nm and with a FWHM = 10 ± 1 nm channel width, the opening half-angle of the radiance meter is 6° in water.

The measurements of L_u were first corrected for the self-shading effect according to [21], then measurements from 0,28 m to 1,5 m were used to extrapolate values for L_u just below the surface. Finally refractive indices as in [22] and a transmittance of 0,98 through the water/air interface were applied to calculate the radiance in air L_u^{air} , giving $L_u/L_u^{air} = 1,709$ at 412 nm and 1,737 at 665 nm. r'_w is then determined according to Eq. 1

$$r'_w = \frac{L_u^{air}}{E_d^{deck}} \quad (1)$$

2.2 Particle scattering, $b_p(440)$

The contribution to the scattering coefficient from particles, b_p , was calculated from measurements of the absorption and scattering coefficients (a and c respectively). a and c was measured as vertical profiles with an AC-9 instrument (manufactured by WETLabs Inc.) at the wavelengths 412, 440, 488, 510, 532, 555, 650, 676 and 715 nm. From these profiles values were manually selected close to the surface and at the half and full Secchi disk depths to determine the relevant values of b_p . No temperature or salinity correction has been performed on the measurements, since this is a minor correction compared with the overall uncertainties of the profiles.

2.3 Other in situ observations and collection of water samples

On all optical stations additional data for the Secchi disk depth (SDD) and wind, sea and sky conditions were collected as well as CTD casts. The SDD was used to determine the water sampling depths according to the protocols. Water samples were collected with a 5 l Niskin bottle at the surface, at the $\frac{1}{2}$ SDD and at the SDD. The water samples were filtered on board for determination of yellow substance (YS), bleached particle absorption (BPA), difference of total and bleached particle absorption ($a_{pig}(442)$), total suspended material (TSM) and chlorophyll-a (Chl2). The maximum vacuum used for the filtration was 300 mm Hg.

Samples to be frozen were submerged on board in liquid nitrogen and transported to the laboratory for freezing in -80 °C until analysis. Samples for YS analysis were stored at $+4$ °C and normally analysed within 3 days except for long cruises.

2.4 Absorption of yellow substance, YS

The YS was measured in a Perkin Elmer Lambda 40P spectrophotometer with a 100 mm cuvette and distilled water as a reference. The attenuation coefficient c of the YS was calculated by the equation

$$2,303 \cdot D = c \cdot r \quad (2)$$

where D is the measured absorbance value, c the attenuation coefficient and r the path length. It is assumed that the absorption coefficient of YS is practically equal to the attenuation coefficient.

2.5 Absorption of particulate material, BPA and $a_{pig}(442)$

Water samples were filtered through $0.7 \mu\text{m}$ 25 mm glass fibre filters (GF/F from Whatman Inc). The diameter of the particulate material on the filters was 15 mm.

The transmission and reflection spectrums of the filters were determined in a Perkin Elmer Lambda 40P spectrophotometer with an integrating sphere from Labsphere with a diameter of 20 mm (model RSA-PE-20), as described in reference [23].

For the bleaching of the filters 3-4 drops of a solution of sodiumhypochlorite (1% active chlor) were applied for approximately 5 minutes, then the filters were flushed with 5 ml of distilled water, and then measured.

The absorption coefficients for the unbleached and bleached filters were calculated as described in reference [23] (note the misprint in the definition of \mathbf{t} , the correct one is shown in Eq. 3.).

$$\mathbf{t} = \frac{1 - T_s^d}{1 - T_s^p} \quad (3)$$

To convert the result into the absorption of particles in a suspension a divisor of 2 (the so called \mathbf{b} factor in reference [19]) was applied.

Pigment absorption a_{pig} was calculated as the difference between the absorption spectrums of the unbleached and bleached filters, adjusting the whole spectrum of a_{pig} so that it became zero at 750nm. Bleached particles absorption BPA was determined directly from the absorption spectrum of the

bleached filter. This value was again added to the absorption coefficient of the YS, and this sum is defined as the yellow substance (YSBPA) in the MERIS protocol [19]. The values of YSBPA are not discussed in this paper (results pending).

2.6 The *in vitro* chlorophyll-a determinations, Chl-a

Water samples were filtered on 47 mm GF/F filters on board the ship and frozen. The chlorophyll-a was determined with the recommended HPLC-method [24, 25] and also with a spectrophotometric determination, partly as a check and partly to obtain data for making a new conversion factor based on this method, since such methods are more common in routine monitoring programs. The MERIS chlorophyll-a products are denoted Chl2 for CASE II water and the corresponding *in situ* values are named either Chl2.hplc or Chl2.sp for HPLC and spectrophotometric determination.

2.7 Total suspended matter, TSM

The measurements of total suspended matter (TSM) were based on the MAVT protocols [19] with improvement on the rinsing of the filters as tested and implemented in the EU-project REVAMP [20]. The rinsing was increased to 3 times 50 ml of distilled water and also 3 times rinsing of the filter rim. This reduced the error of the TSM to approximately 15%.

2.8 Validation of the *in situ* measurements and laboratory methods

Several intercomparisons of both *in situ* instruments and laboratory methods have been performed before and under the validation campaigns. The intercomparison of pigment methods was made in NIVACal 1 and 2 [26, 27] and as a part of the EU-project REVAMP [20], the two workshops PlymCal I and II as well as bilateral intercomparisons within this project.

3 RESULTS

3.1 Relations between optical quantities and concentrations of TSM and Chl-a

The processing of the MERIS L2 data products for CASE II waters (Chl2, TSM) is based on the factors converting the neural network output (NN) to the optical quantities $a_{pig}(442)$ and $b_p(442)$ [24]. The data used to train the NN are from the Helgoland area. They have been collected monthly at several stations for a period of two years as part of the COLORS and MAPP projects. For the computation of the data set of water-leaving radiance reflectance, which has been used for training of the NN, the variability of the optical properties within the two years time series has been taken into account.

The results of the phytoplankton pigment absorption, $a_{pig}(442)$ versus the chlorophyll-a concentration (Chl2.hplc) from the Skagerrak area are shown in Fig. 2. The figure also presents the average relation for the Helgoland data. The chlorophyll-a conversion factor is lower in the Skagerrak while the exponent is approximately the same. If this is correct, it means that the MERIS Chl2 data products on an average will overestimate the chlorophyll-a in the area with a factor of 3.

The results of the scattering of particles, $b_p(440)$, are shown in Fig. 3 and are in relative good agreement with the reference model data from Helgoland. This means that the MERIS TSM data products should be in good agreement with the *in situ* data. As seen in the figure some data around 2 g m⁻³ of TSM and between 1.5 and 2.0 $b_p(440)$ are from an inner area of the Hvaler archipelago. Removing these data the fit would be even better compared to the reference model.

Investigation of the slope of bleached particles (BPA) for the open area of Skagerrak reveals values around $-0.0089 \pm 0.00236 \text{ nm}^{-1}$ (N=34). This is slightly higher than the corresponding value $-0.0072 \pm 0.00108 \text{ nm}^{-1}$ from the Helgoland data [24], indicating more absorption from coloured particulate detritus.

The yellow substance (YS) data from the investigation in 2002 are to be work up and are therefore still pending, but older data from monitoring data in the area show a slope for the upper 10 meter equal to $-0.0111 \pm 0.0025 \text{ nm}^{-1}$ (salinity 27.9 ± 3.6 , $a_{442} = 0.34 \pm 0.080 \text{ m}^{-1}$, N = 105). This is lower than the YS slope $-0.0138 \pm 0.0028 \text{ nm}^{-1}$ found for Helgoland and used in the neural network. This will be confirmed with the pending data from the 2002 when the data analysis is completed.

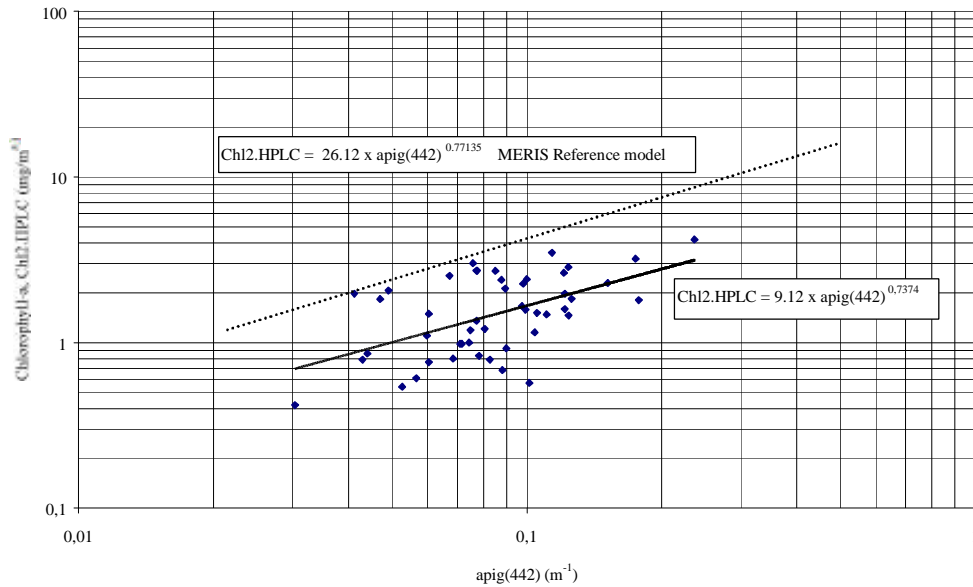


Fig. 2. The relation of $a_{pig}(442)$ and chlorophyll-a concentration (Chl2) compared to the relation used in the reference model for CASE II water based on the Helgoland data.

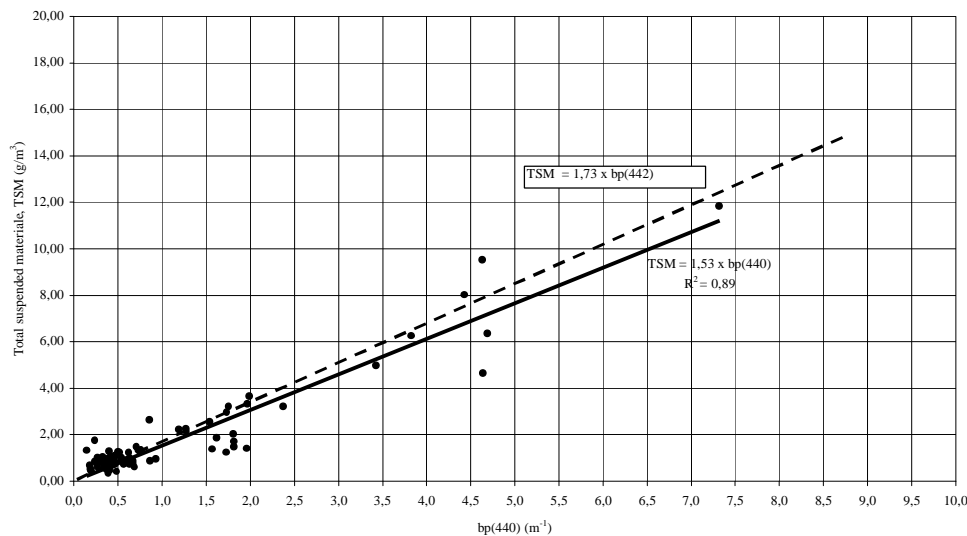


Fig. 3. The relation of $b_p(440)$ and total suspended material (TSM) for the Skagerrak area compared to the reference model based on Helgoland data.

3.2 Validation of MERIS L2 data

Table 1 shows the possible match-ups from the 11 MERIS L2 images that have been investigated. The results show that for most of the situations both products flags (P) and science flags (S) were turned on and all match-up data were contaminated by sun-glints as indicated by the medium sun-glint flags. In two situations also the high sun-glint flag was raised, and for most of the situations the science flags for the atmospheric correction were turned on.

Table 1. Overview of possible match-ups in the Skagerrak area in 2002.

Date	In situ Rho_w	rho_w_Flag (PCD1_13)	In situ Chl2	Chl2_Flag (PCD_17)	In situ YSBPA	YSBPA_Flag (PCD_16)	In situ TSM	TSM_Flag (PCD_16)	MEDIUM_GLINT	HIGH_GLINT	ABSOA_CONT	CAMERA_NO
07.05.2002	1	P	1	P	1	P	1	P	S			2
11.05.2002			1	P	1	P	1	P	S		S	3
02.06.2002			1	P	1	P	1	P	S		S	3
05.06.2002		P	1	P	1	P	1	P	S		S	3
24.06.2002	1	P	1	P	1	P	1	P	S	S	S	2
25.06.2002	1	P	1	P	1	P	1	P	S			4
27.06.2002	1	P	1	P	1	P	1	P	S	S	S	4
03.07.2002	1	P	1	P	1	P	1	P	S		S	4
17.07.2002			1	P	1	P	1	P	S		S	4
01.08.2002	1		1	P	1	P	1	P	S		S	2
18.09.2002		P	1	P	1	P	1	P	S		S	2

P = Product Confidence Flag TRUE=BAD
 S = Science Flags TRUE=BAD
 HIGH_GLINT=High sun-glint at the station
 MEDIUM_GLINT= Medium sun-glint at the station
 ABSOA_CONT= Atmospheric correction failed
 CAMERA_NO= MERIS camera, high number West in the swath

On the 25th of June only the medium sun-glint flag was turned on, and the *in situ* observation was at the west side of the MERIS swath (camera 4). In Fig. 4 an example of the water leaving reflectance, r'_w , determined from our field measurements and from MERIS L2 Reduced Resolution data from this date are shown. We have picked out the values of r'_w at one pixel, and we have also calculated the average value using nine and twenty-five pixels.

It is clear from the figure that MERIS in this example resembles rather well the shape and value of r'_w . It also seems to be a trend that the result from MERIS becomes better when an increasing number of pixels are used.

The results presented in the figure are those that produce the best match between our field data and the MERIS measurements. Tab. 1 shows that this date is the best one with respect to the area with lowest sun-glint problems (west side of the MERIS swath) and the flags for high sun-glint and absorbing aerosols. In all the other match-ups the value of r'_w is higher in the MERIS product than in our field measurements.

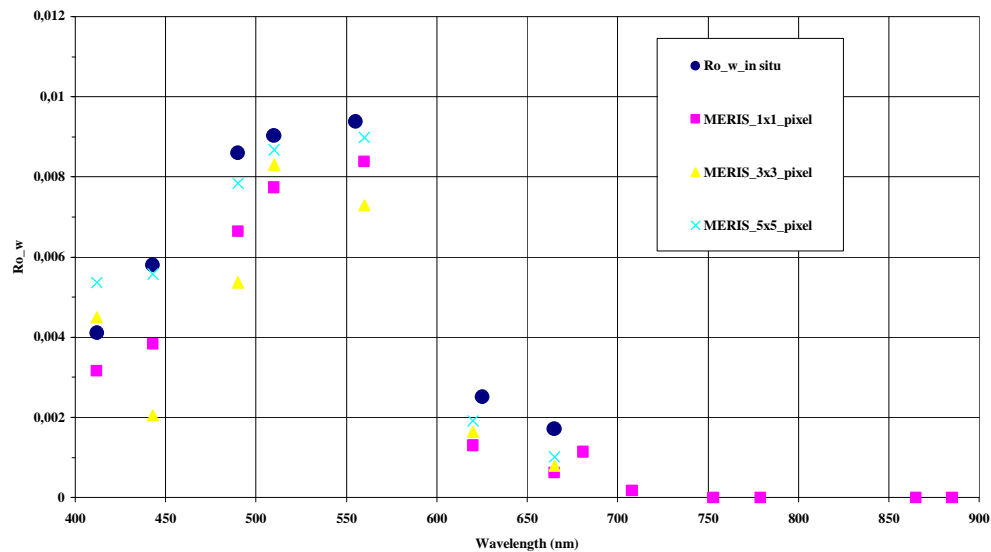


Fig. 4. MERIS water-leaving reflectance compared to *in situ* data on the 25th of June 2002 in the Skagerrak/Kattegat area.

For this situation the MERIS.Chl2 and MERIS.TSM are in good agreement with *in situ* data (Chl2.hplc and TSM.dryw), as seen in Tab. 2. For other dates the TSM is in the same concentration range, but the Chl2 products vary and on an average the Chl2 values from MERIS are a factor 2 higher than the *in situ* data. This is caused by the failure of the atmospheric correction and must be analysed with new reprocessed data.

Tab. 2. MERIS L2 CASE 2 data products for possible match-ups in the Skagerrak/Kattegat area in 2002 compared to *in situ* data. Chl2.hplc and MERIS.Chl2 in mg m^{-3} , TSM.DRYW and MERIS.TSM in g m^{-3} .

Date	Chl2.hplc	MERIS.Chl2	TSM.DRYW	MERIS.TSM
11.05.2002	1,33	4,11	0,66	1,08
24.06.2002	1,15	3,13	0,87	1,24
25.06.2002	2,41	2,03	0,76	0,60
27.06.2002	0,98	2,52	0,75	1,85
03.07.2002	1,84	1,72	0,60	0,65
17.07.2002	3,41	5,40	1,55	0,96
01.08.2002	0,84	2,66	0,81	0,87

4 DISCUSSION AND PRELIMINARY CONCLUSIONS

The relation between suspended material, TSM, and the scattering coefficient of particles, $b_p(440)$ shows good agreement with the findings from the Helgoland area, and the MERIS conversion factor of 1,73 can be used in the Skagerrak. Despite this match it is noteworthy that the TSM values may be under- and overestimated with 75% by the line, particularly at low values, as seen in Fig. 3.

The phytoplankton pigment absorptions $a_{pig}(442)$ versus the *in situ* chlorophyll-a concentrations (Chl2.hplc) from the Skagerrak produce another relation than the one used in the reference model. The intercept of the relation is a factor 3 lower than for the Helgoland data, but have the same slope, as seen in Fig. 2. The explanation for this is not yet fully understood. Any error of this magnitude due to the HPLC or particle absorption methods is unlikely, since both methods have been tested and inter-compared with other laboratories. Only our HPLC chlorophyll-a data have for some of the inter-comparisons been about 20 % lower than the highest values of the other laboratories. The finding here must be confirmed with new data and analysis.

From this and the preliminary comparison of MERIS CASE II Chl2 products and *in situ* data we conclude that MERIS seems to overestimate the chlorophyll-a within the investigated area. This result has to be tested with new reprocessed MERIS data, since e.g. the MERIS data from the situation of June 25th is in good agreement with the *in situ* data.

The water-leaving reflectance r'_w seems to be overestimated when the flags for absorbing aerosol are raised. For the single match-ups from June 25th without such a flag r'_w is underestimated, for all other dates the MERIS processing overestimates this product. Particularly in the blue part of the spectrum the overestimation becomes large, in the red part the relative error is high. Sun glint may also cause significant errors, since at least the eastern part of an image may be contaminated, depending on the wind. This influence has to be investigated using data from two consecutive passes, where the same area is viewed with and without sun glint.. Due to the atmospheric correction problem all the MERIS data have to be reprocessed and the validation repeated on the new data.

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