

MERIS VALIDATION OF GEOPHYSICAL OCEAN COLOUR PRODUCTS: PRELIMINARY RESULTS FOR THE NETHERLANDS

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ABSTRACT

Three field cruises were performed in 2002 for the validation of the geophysical ocean colour products of the MERIS sensor on board ENVISAT. At each cruise four stations were visited, where one of the stations was optimised to coincide with a MERIS overpass. Cloud-free sky conditions were realized during two cruises in April and September. For the cruise of 2 September 2002 a level-2 MERIS image was received and the geophysical products were compared with the in situ measured parameters. Two stations were measured within 1 hour of the MERIS overpass (1 and 50 minutes difference). The reflectance and suspended sediment concentration retrieved from the MERIS image were reasonably consistent with in situ observations. The MERIS algal pigment 2 was significantly higher and the yellow substance absorption was significantly lower than the in situ observations.

Only two match-up pixels are presented in this paper, so no statistically sound conclusive remarks can be made about the validation level of MERIS for the geophysical products that are discussed. Combination with other match-up pixels under different atmospheric conditions and for different concentration ranges are necessary to gain more insight in the MERIS accuracy. More in-depth research is needed to understand the nature of the differences between in situ and MERIS observations.

1. INTRODUCTION

In March 2002, the European Space Agency launched ENVISAT, a polar-orbiting Earth observation satellite that provides measurements of the atmosphere, ocean, land, and ice. The MEdium Resolution Imaging Specrometer Instrument (MERIS) on board ENVISAT is dedicated to measurements of sea colour in the oceans and in coastal areas. Knowledge of the sea colour can be converted into a measurement of chlorophyll pigment concentration, suspended sediment concentration and yellow substance absorption over the marine domain. There is a Dutch interest in validated MERIS products for management of the coastal waters. Chlorophyll concentration and suspended matter concentration are regarded as key parameters in the study of phenomena such as eutrophication, harmful algae blooms, but also for the study of the effects of human interventions in the coastal area. Dutch national ship time was made available to the IVM team to participate in the validation of the MERIS water products in the framework of several research projects. The objectives of the field studies can be summarised as:

- 1) to assess the accuracy of MERIS water products by making match-up measurements
- 2) to report similarities and discrepancies to the European Space Agency
- 3) to make recommendations to the European Space Agency about product improvements
- 4) to inform the Dutch user community on the status and usefulness of MERIS products

During the in-situ measurement campaigns data was acquired on water leaving reflectance, chlorophyll concentration, total suspended matter, yellow substance absorption and on inherent optical properties per station. In the analysis of MERIS imagery, also attention was given to some atmospheric parameters.

This paper describes the methodology and protocols used during the field sampling campaigns and the results of the comparison of MERIS observations with in-situ measurements.

2. METHODOLOGY

2.1 Cruise planning

The Institute for Environmental Studies was able to join the monitoring cruises in 2002 of the North Sea Directorate (a regional department of the Dutch Directorate-General of Transport, Public Works and Water Management) on a regular basis, provided it did not hamper the standard monitoring program. In practice, we were allowed to participate in one- or two-day cruises covering the so-called 'Noordwijk' transect, running from 2 to 70 kilometre offshore Noordwijk (52°15'N, 4°26'E). The decision to participate in a given cruise was determined by the prediction of the MERIS orbits and the weather conditions. This flexible approach was followed to maximise the chance of valid MERIS validation match-up stations with limited effort. The cruise overview is given in Table 1. Effectively 3 out of 15 cruises were

joined, where the cruises of 8 April and 2 September had excellent weather and a MERIS overpass. The cruise of 3 June had cloudy weather and no MERIS overpass, but was carried out to improve the continuity over the summer of the measurements of concentrations and inherent optical properties. During each cruise four stations were visited, where one of those stations was synchronised with the predicted MERIS overpass.

2.2 Protocols

At each station a water sample was taken with a rosette sampler at 1 m depth, simultaneously with a surface reflectance measurement with a PhotoResearch PR650 spectroradiometer. Immediately after sampling the additional parameters were recorded, including wind speed and direction, time (UTC) and geographic position in UTM 31U projection, relative humidity, surface pressure, sky coverage, wave height, Secchi Disk depth, and any other observations that seemed relevant. Digital photos of sky and water coverage were also taken.

Reflectance is measured at least three times as quick as possible (typically within 3 minutes) to reduce effects of changing water masses and illumination conditions. Preferable position on the ship is on the bow, to minimize surface wave effects and shading and/or reflectance from the ship's superstructure. Each reflectance measurement consists of four radiance measurements (1) radiance emanating from the water surface L_t ; (2) radiance from the sky L_{sky} ; (3)

radiance from the reflectance standard L_p ; (4) radiance from the shaded reflectance standard L_{pr} . A radiance measurement is an average of five readings, internally averaged by the radiometer. Measurement geometry is in accordance with findings by Mobley (1999) to minimize sky-reflectance as a function of wind speed. The view zenith and view azimuth (with respect to the sun) are $\theta_v = 40^\circ$ and $\phi_v = 135^\circ$, respectively. The sky radiance is measured (same geometry, but upward) to correct the total surface radiance for sky radiance reflected at the sea surface to yield water-leaving radiance $L_w = L_t - \rho_{sky} L_{sky}$, where ρ_{sky} is the effective Fresnel reflection coefficient for the wind-roughened sea surface. The radiance measurement of the reflectance standard is used to calculate above-water

downwelling irradiance $E_{ad} = \pi \frac{L_p}{\rho_{panel}}$, where ρ_{panel} is the reflectance of the reflectance standard (~99%). The

standard is measured under an angle of 45 degrees. The reflectance can then be calculated as $\rho_w = \frac{\pi L_w}{E_{ad}}$. The

measurement of the shaded reflectance panel is not required for calculating MERIS reflectance, but can be used to get a handle on the downwelling radiance distribution (specifically the fraction diffuse/total downwelling irradiance F), which serves as input in numerical radiative transfer code such as Hydrolight.

Within half an hour after sampling the water was filtrated for the total suspended matter concentrations, the chlorophyll concentrations and the CDOM or yellow substance measurements. The chlorophyll filters were stored on board at less than -20°C , the raw water sample and filtrated water was stored in the dark at 4°C . After transportation to the laboratory the samples were analysed by a Dutch private company, AquaSense, for the following parameters within one day

1. total suspended matter concentration: filtration on a Whatmann GF/F pre-ashed (450°C) filters, rinsed with 3x50ml MilliQ, and dried at 70° for 1 hour. Each sample was measured in tri-replicate;
2. chlorophyll-a concentration*: spectrophotometric method according to Dutch standard protocol (NEN 6520, 1981), each sample was measured in tri-replicate. For the MERIS validation the chlorophyll concentration was not corrected for phaeopigments;
3. beam attenuation was measurement in a 10 cm cuvet using a single beam Ocean Optics spectrometer, referenced against milliQ;
4. yellow substance absorption was measured after filtration over a Whatmann GF/F filter, in a 10 cm cuvet using an Ocean Optics spectrometer
5. (bleached) particle absorption was measured with the filterpad method (Trüper and Yentsch, 1967) on a Whatmann GF/F filter using an Ocean Optics spectrometer.

The phytoplankton pigment absorption was calculated as the difference of the particle absorption before and after bleaching. The particle scattering was calculated as the difference of the beam attenuation and the total absorption (particle absorption + yellow substance absorption). The protocols were updated in 2002 to comply as much as possible with REVAMP and MERIS validation protocols (Tilstone and Moore, 2002; Doerffer, 2002).

* The Aquasense CHL-a measurements have been compared to other MAVT labs in the NIVAcAl round robin experiment.

2.3 Used software & tools

All digital image processing was performed using Matlab 6.5 (R13). The MERIS measurement datasets were imported into Matlab using the MATBX (0.8.4) Java API (a prior version of BEAM 1.0). The appropriate row- and column indices for the match-up pixels were found by triangle-based, cubic interpolation in the latitude and longitude tie-point grids.

3. AVAILABLE IMAGERY

In advance of the Envisat validation workshop in Frascati (9-13 December 2002) we received a MERIS image that was acquired on 2 September 2002 at 10:29:52 UTC. A true-colour quick look of the image of 2 September is given in Fig.1. The image was processed using the latest 'smile' correction and with the absorbing aerosol models switched off.

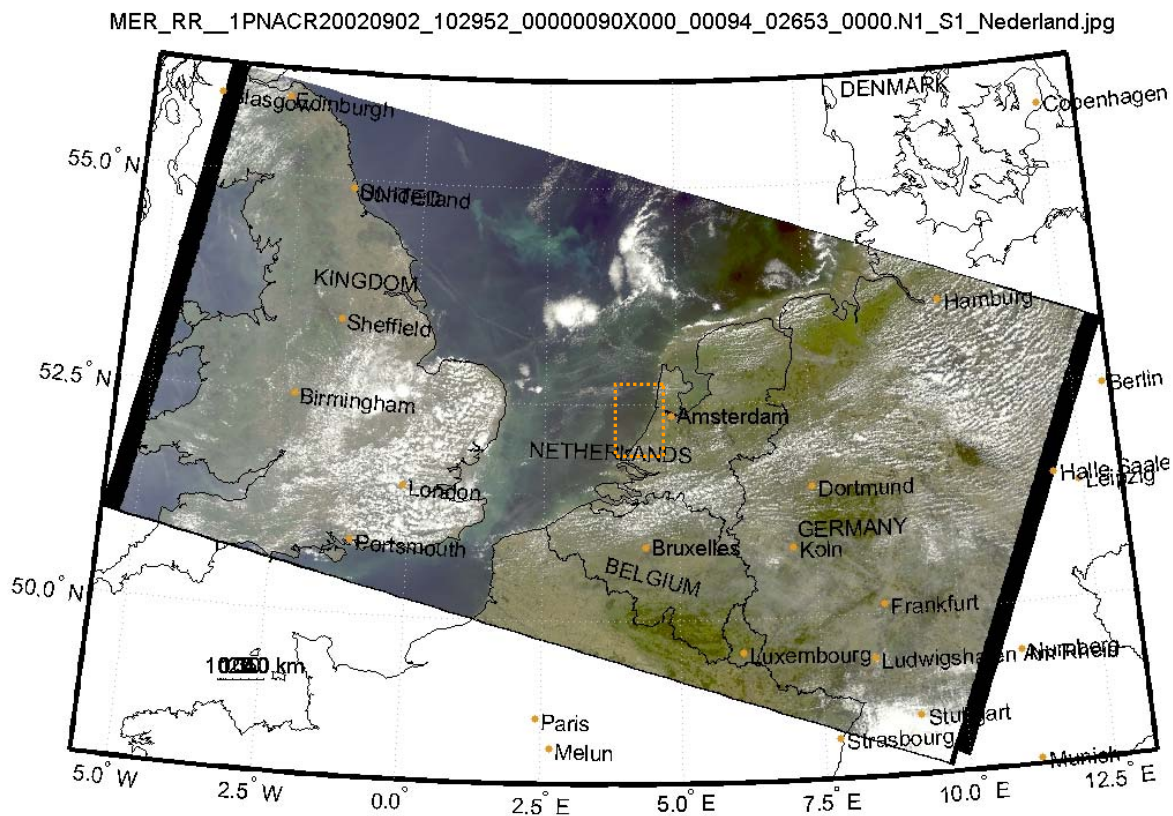


Fig.1. True-colour quick look of the MERIS image acquired 2 September 2002 at 10:29 above the North Sea. The subset of the image presented in Fig. 5 is indicated by an orange dotted rectangle.

The atmosphere was very clear at the time of MERIS overpass. A CIMEL station close (less than 15 km) to the match-up location indicated values of aerosol optical thickness of 0.1 (courtesy Marcel Moerman, TNO-FEL), as indicated in Fig. 2.

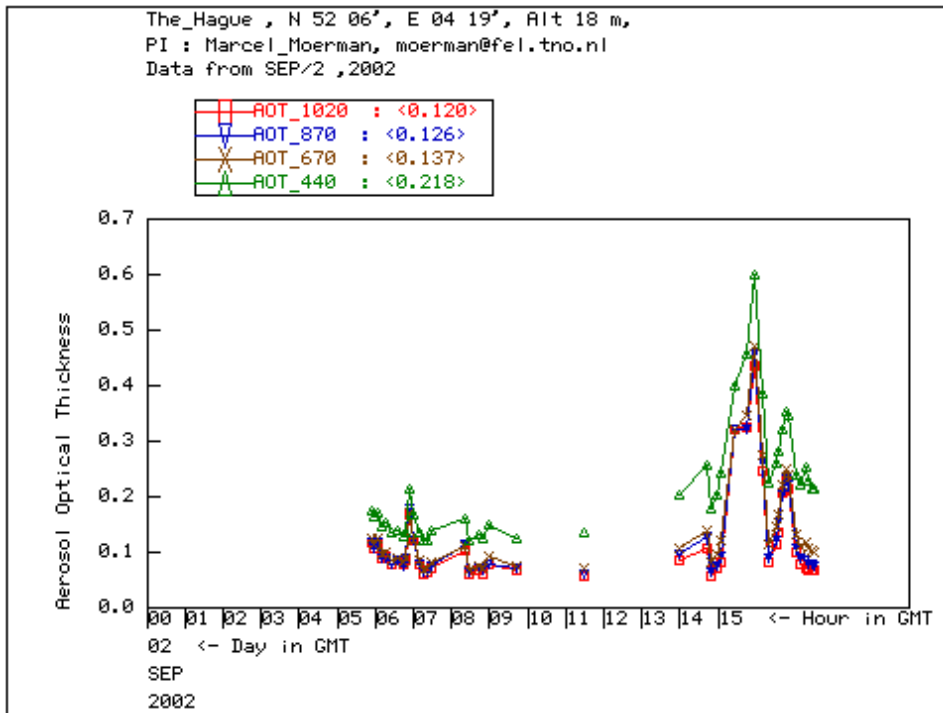


Fig. 2. AeroNet data (CIMEL) for the ‘The Hague’ station (data courtesy Marcel Moerman, TNO-FEL).

The low aerosol content is also supported by the MERIS level 2 aerosol optical thickness product that gives the same value (~0.1). Wind speed data was available very close (less than 10 km) to the match-up station, indicating that a moderate breeze (6 ms^{-1}) was blowing from the East (data courtesy KNMI).

4. RESULTS

Of the four stations that were visited on the second of September, two fall within 1 hour of the MERIS overpass (10:29 UTC). Station 1 was sampled at 10:30 and Stations 2 was sampled at 11:20 UTC. The corresponding match-up pixels that were identified for the 2 September image are given in Table 2 (geometries) and Table 3 (flag values). The match-up locations, the CIMEL station and the wind speed station are indicated in a subset of the MERIS image in Fig. 5.

Both stations are close to the coast, and patterns of suspended sediment are visible within the true colour image. Because the pixels are located in the middle of the MERIS swath, they have near-nadir viewing geometry (camera 3), which might result in medium sunglint (the ‘medium_glint’ flag was raised). Both pixels also have the case2 flag raised. The in situ concentrations and relevant inherent optical properties that were measured at both match-up stations are presented in Table 6 and compared with the MERIS pixels and a 3x3 pixel box around the match-up pixels to indicate the variance in the MERIS values due to between-pixel natural variability. This between pixel variations must be taken into account because geo referencing is typically performed with an uncertainty of approximately one pixel. For station 1 we compared both in situ concentrations and reflectance, but for station 2 the PCD flags were raised for the concentration products, so we only compared reflectance.

4.1 Concentrations

When comparing the in situ measured concentrations, we see that, for station 1, the chlorophyll-a concentration measured in situ (5.8 and 6.4 for the optical method and the spectrophotometric method, respectively) is significantly lower than the MERIS algal pigment index 2 for the nearest neighbour pixel (9.8) and also lower than the minimum found for the 3x3 box surrounding the nearest neighbour pixel (8.3). The TSM concentration measured in situ (4.2 and 3.6 for the optical method and the gravimetric method, respectively) is within 25% of the MERIS total suspended matter product (4.4) and (almost) falls within the minimum and maximum value (3.7 and 6.6) found in the 3x3 pixel box around the nearest neighbour pixel. The yellow substance absorption at 442nm measured in situ (0.53) is significantly higher than the MERIS yellow substance product (0.20) and falls outside the minimum and maximum value (0.18 and 0.34) found in the 3x3 pixel box around the nearest neighbour pixel.

4.2 Reflectance

The comparison of the reflectance is based on the spectra found within the 3x3 box of pixels around the match-up (nearest neighbour) pixel in the MERIS image, and the tri-replicate of reflectance measurements made by the above water radiometry measured from the ship. No conversions were made to correct for the geometry differences between MERIS (near nadir) and the reflectance measured from the ship (40° nadir angle). The reflectance for station 1 and 2 are presented in Fig. 3 and Fig. 4, respectively. The three spectra that were measured in situ are presented as three blue lines. The minimum and maximum MERIS reflectance are presented as thin orange lines, the match-up pixel reflectance is presented as a dotted thick orange line and the median of the 3x3 pixel box is presented as a thick orange line. The hyperspectral reflectance data was converted to MERIS bands using the appropriate MERIS spectral response curves.

For both stations there is an overlap between the three blue lines (in situ spectra) and the minimum and maximum values found within the 3x3 pixel box, which means that the MERIS reflectance is consistent with the in situ measured reflectance. For band 1 to 5 the difference between the mean in situ spectrum and the MERIS match-up reflectance is smaller than 0.005, for band 6 to 11 the difference is smaller than 0.001.

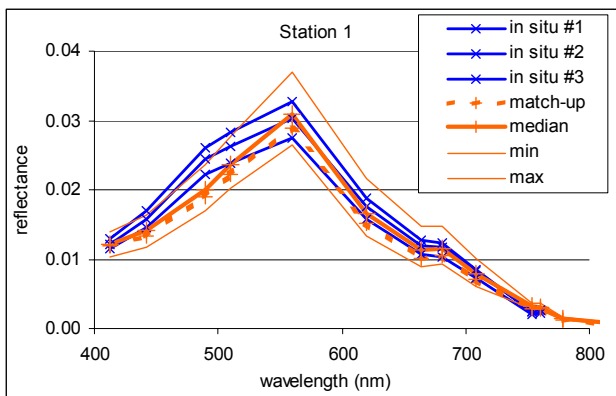


Fig. 3. Comparison between in situ measured reflectance and MERIS derived reflectance for station 1. The median, minimum and maximum values are calculated over a 3x3 pixel box around the match-up pixel.

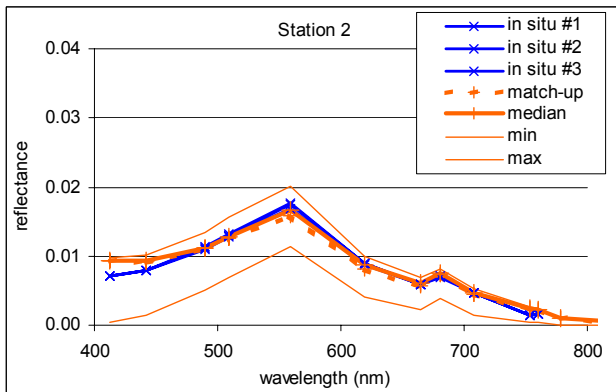


Fig. 4. Comparison between in situ measured reflectance and MERIS derived reflectance for station 2. The median, minimum and maximum values are calculated over a 3x3 pixel box around the match-up pixel.



Fig. 5. Map of match-up stations, CIMEL location, and wind speed station plotted on top of the MERIS image (true colour) of 2 September 2002.

5. CONCLUSIONS AND RECOMMENDATIONS

For two match-up pixels it was found that the reflectance values and the suspended matter concentrations were consistent with in situ observations. The algal pigment 2 was significantly higher and the yellow substance absorption was significantly lower than the in situ observations. For band 1 to 5 the difference between the mean in situ spectrum and the MERIS match-up reflectance is smaller than 0.005, for band 6 to 11 the difference is smaller than 0.001.

Only two match-up pixels are presented in this paper, so no statistically sound conclusive remarks can be made about the validation level of MERIS for the geophysical products that were discussed. Combination with other match-up pixels under different atmospheric conditions and for different concentration ranges are necessary to gain more insight in the MERIS validation. On the other hand also more in-depth research is needed to understand the nature of the differences between in situ and MERIS observations.

In future, the following points should be addressed to improve the knowledge on MERIS validation

1. processing and delivery of more MERIS scenes to provide more match-up stations and to allow a better statistical approach to MERIS validation.
2. investigate the influence of MERIS degradation on the level 2 geophysical products
3. have a closer look at the atmospheric correction performance, especially above complex case II waters in the blue part of the spectrum.
4. investigate full resolution MERIS products to get a better understanding of between and sub pixel variation
5. compare MERIS products with historical in situ data to investigate possible systematic biases in the level 2 products
6. perform vicarious calibration of MERIS with other ocean colour sensors such as SeaWiFS and MODIS.
7. continue validation-cruises in 2003 to get more potential match-up stations.

6. ACKNOWLEDGEMENTS

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would like to thank the staff, captain and crew of the M/S Mitra for their flexibility and kindness. Finally we thank the ESA and Brockmann Consult for the delivery of (match-up) MERIS imagery.

7. TABLES

Table 1. Cruise overview for 2002

date	status	Date	status
25-Mar	skipped	29-Jul	skipped
8-Apr	joined	5-Aug	skipped
29-Apr	skipped	12-Aug	skipped
6-May	skipped	19-Aug	skipped
27-May	skipped	26-Aug	skipped
3-Jun	joined	2-Sep	joined
24-Jun	skipped	16-Sep	skipped
1-Jul	skipped		

Table 2 Overview of the viewing geometry (degrees) and location (DMS) of the match-up pixels.

	Lat:	Lon:	sun zenith	sun azimuth	view zenith	view azimuth
STATION 1	52°10'32" N	4°15'58" E	47	155	4	287
STATION 2	52°14'21" N	4°16'55" E	47	155	4	287

Table 3 Overview of relevant flag values for the match-up pixels.

	reflec	alg. pig. 1	ys, spm	alg. Pig. 2	ABSOA_CONT	ABSOA_DUST	CASE2_S	CASE2_Y	MEDIUM_GLINT	HIGH_GLINT
STATION 1	FALSE	TRUE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE
STATION 2	FALSE	TRUE	TRUE	TRUE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE

Table 4 Statistics for relevant and valid (no PCD flag raised) MERIS geophysical products extracted from the MERIS image for station 1. The mean, median, min and max were calculated over a 3x3 pixel box around the nearest neighbor pixel.

Product	nearest neighbor	mean	median	min	max
reflec_1	0.012	0.012	0.012	0.010	0.014
reflec_2	0.013	0.014	0.014	0.012	0.016
reflec_3	0.019	0.020	0.020	0.017	0.024
reflec_4	0.022	0.024	0.024	0.020	0.028
reflec_5	0.029	0.031	0.031	0.026	0.037
reflec_6	0.015	0.017	0.017	0.013	0.022
reflec_7	0.010	0.012	0.011	0.009	0.015
reflec_8	0.011	0.012	0.011	0.009	0.015
reflec_9	0.007	0.008	0.008	0.006	0.010
reflec_10	0.003	0.003	0.003	0.003	0.004
reflec_11	0.003	0.003	0.003	0.003	0.004
reflec_12	0.001	0.001	0.001	0.001	0.002
reflec_13	0.000	0.000	0.000	0.000	0.000

algal_2	9.8	9.4	9.3	8.3	10.4
yellow_subs	0.20	0.254	0.256	0.177	0.335
total_susp	4.4	5.1	4.9	3.7	6.6

Table 5 Statistics for relevant and valid (no PCD flag raised) MERIS geophysical products extracted from the MERIS image for station 2. The mean, median, min and max were calculated over a 3x3 pixel box around the nearest neighbor pixel.

Product	nearest neighbor	mean	median	min	max
reflec_1	0.009	0.007	0.009	0.001	0.010
reflec_2	0.009	0.008	0.009	0.001	0.010
reflec_3	0.011	0.010	0.011	0.005	0.013
reflec_4	0.013	0.012	0.013	0.007	0.016
reflec_5	0.016	0.016	0.017	0.011	0.020
reflec_6	0.008	0.008	0.009	0.004	0.010
reflec_7	0.006	0.005	0.006	0.002	0.007
reflec_8	0.007	0.007	0.008	0.004	0.008
reflec_9	0.004	0.004	0.005	0.001	0.005
reflec_10	0.002	0.002	0.002	0.000	0.003
reflec_11	0.002	0.002	0.002	0.000	0.002
reflec_12	0.001	0.001	0.001	0.000	0.001
reflec_13	0.000	0.000	0.000	0.000	0.000

Table 6 In situ parameters for station 1 and 2

Parameter	Station 1	Station 2
chl-a, spectrophotometric (mgm^{-3})	6.4	8.2
phytoplankton pigment absorption at 442 nm (m^{-1})	0.142	0.209
chl-a ¹ calculated from pigment absorption (mgm^{-3})	5.8	7.9
total suspended matter (gm^{-3})	3.6	3.7
particle scattering (m^{-1})	3.1	2.0
total suspended matter ² (gm^{-3})	4.2	2.7
yellow substance absorption at 442 nm (m^{-1})	0.53	0.54

¹ using a conversion factor of $chl = 26.212 \cdot a_{pig}(442nm)^{0.77135}$

² using a conversion factor of $TSM = 1.73 \cdot b_p$

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