ABSTRACT

Two MERIS scenes of case 2 water of the German Bight have been compared with measurements from ship. These first very preliminary tests have indicated that the atmospheric correction in the blue part of the MERIS spectrum is not sufficient. An alternative atmospheric correction, using a neural network, produces water leaving radiance reflectances, which are much closer to ship measurements. However, although the MERIS L2 processor indicates that the reflectance spectra are out of range, the derived concentrations show relative profiles along ship transects, which are still in reasonable agreement with observations.

Most critical for further work is the atmospheric correction, including investigations on the impact by Rayleigh scattering, cirrus clouds and sun glitter. Furthermore, due to the high patchiness of substances in the German Bight, full resolution data are necessary to get a better comparison between water samples and MERIS data and their variances.

OVERVIEW ABOUT VALIDATION ACTIVITIES AND AVAILABLE DATA

The GKSS MERIS validation team has carried out a number of cruises during the spring-summer period of 2002 for the validation of MERIS level 2 data of coastal waters. They are listed along with the MERIS scenes, which were available until end of 2002, in Table 1. The weather of this period was mainly cloudy so that the number of blue sky days with a MERIS overpass was small. Only between mid August and end of September we had some stable periods, where validation experiments could be planned. Another limitation was that only two corrected MERIS scenes for which match up data exists were provided by ESA, shortly before the validation workshop. In addition to the level 2 scenes, which were produced with the MERIS processor, we have evaluated the scene of July 29, level 1b, with an experimental breadboard processor. It uses the same neural network for the retrieval of the optical properties of water constituents but has an alternative procedure for atmospheric correction, which is also based on a neural network.

Our main validation cruise was carried out with the research vessel "Heincke" from April 23 to May 2. This period was chosen to cover the main phytoplankton bloom in the North Sea. When the application for this ship has to be made early 2001, the launch date for ENVISAT was still 2001. Unfortunately, MERIS data are now available only from April 29 on. A map of the stations is given in Fig. 1.

Due to the cloudy weather during the summer 2002 we decided to change the strategy and do the validation measurements from a ship of opportunity, i.e. the ferry boat "Wappen von Hamburg", which operates daily between Cuxhaven and the island of Helgoland (s. Fig. 2). Advantage was that the decision for a cruise could be made on very short notice, disadvantage was that the ship cannot stop during the cruise for measuring vertical profiles. The water types, which are covered by this transect, ranges from turbid estuarine water at Cuxhaven to clear blue-green water around Helgoland so that a variety of different water constituents are covered by one match-up scene. Problem is that the distribution is very patchy.

Further data for the validation exist from measurements with the GKSS ferry box. It is installed on the ferry boat, which sails between Cuxhaven and Harwich. This box consists of an autonomous package of instruments, which measure continuously variables such as temperature, salinity, turbidity, fluorescence of phytoplankton and nutrients so that transects of these variables exist for nearly every day.

Beside the ship cruises we have operated a CIMEL sun photometer on the island of Helgoland for the validation of the atmospheric correction. It is part of AERONET, the global network of sun photometers for aerosol research.

The validation was focussed on the water leaving radiance reflectance product, which is produced by the atmospheric correction procedure and which is critical for the success of the NN algorithm. In a further step we have compared the derived concentrations with in situ measurements.
<table>
<thead>
<tr>
<th>Date / Period</th>
<th>Ship</th>
<th>area</th>
<th>Instruments /variables</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.4. - 2.5.2002</td>
<td>Heincke</td>
<td>South-eastern North Sea</td>
<td>- Satlantic, AC-9, BB4, Trios-raft&lt;br&gt;- CTD, pigments, SPM, ISPM, OSPM, DOC, POC, filterpad absorption&lt;br&gt;- Fluorescence and primary production</td>
<td>46 stations, only few days with blue sky, MERIS scene available for 29.4.</td>
</tr>
<tr>
<td>29.07.02, 30.07.02, 14.08.02, 15.08.02, 03.09.02</td>
<td>Wappen von Hamburg</td>
<td>Cuxhaven-Helgoland transect</td>
<td>Trios above water reflectance, T, S, pigments, SPM, ISPM, OSPM, DOC, POC, filterpad absorption</td>
<td>All days with blue sky and ENVISAT overpass, MERIS scenes available for 29.7. and 14.8.</td>
</tr>
<tr>
<td>Daily April - October</td>
<td>Helgoland</td>
<td></td>
<td>CIMEL sun photometer for aerosols, PAR</td>
<td>Only for blue sky days</td>
</tr>
<tr>
<td>Daily until October</td>
<td>Ferry</td>
<td>Cuxhaven - Harwich</td>
<td>Turbidity, phytoplankton fluorescence, T, S, nutrients</td>
<td>Ferry Box</td>
</tr>
</tbody>
</table>

Table 1 Overview about validation activities of the GKSS MERIS validation team in 2002

Fig. 1 Stations during the cruise #167 with RV "Heincke", April 23 - May 2, 2002

Fig. 2 Transect Cuxhaven – Helgoland (blue line) covered by the ferry boat "Wappen von Hamburg"
METHODS AND INSTRUMENTS FOR THE VALIDATION

During the cruise with RV "Heincke" a full suite of measurements of water constituents and inherent and apparent optical properties were performed on all stations. The methods are based on the protocols for MERIS validation [1] and have been intercompared within the MAV-team during the intercalibration exercises (s. the corresponding reports in this volume). The bio-optical model and the algorithm, which are used to produce L2 concentration data of case 2 water are described in [2] this volume and [3], a detailed description of the neural network algorithm is given in [4].

During the cruises with the "Wappen von Hamburg" only above water reflectance measurements could be performed and samples could be taken only from the water surface.

RESULTS

Only two scenes, of July 29 and August 14, were made available to us for validation. For comparing the water leaving radiance reflectances, we have extracted transects from the MERIS scenes according to the GPS positions of the ship transects by using the BEAM MERIS VISAT software.

![Fig. 3 MERIS scenes of July 29 (a, left) and August 14 (b, right), section of the German Bight, with ship transect](image)

Separation between atmospheric path radiance and water leaving radiance reflectance

One indication for a successful atmospheric correction is the difference between the path radiance and the water leaving radiance along a transect, where strong gradients or fronts occur either in the water or the atmosphere or both. The shape of both curves should normally not be correlated. We have applied this test to the scene of July 29 (Fig. 4). The pixel index from left to right runs along the transect from Cuxhaven to Helgoland. The curves RL_path (path radiance reflectance) and RLw_bread (water leaving radiance reflectance) for MERIS band 9 were produced using the breadboard processor. RLw_L2 is the water leaving radiance reflectance from the MERIS L2 processor.

Obviously, the separation works with both methods. However, the MERIS standard product shows a higher covariance between the path and water leaving radiance reflectances and the RLw is significantly higher. Furthermore, there are some gaps in the transect, which cannot easily be explained. Because of the flags (s. Fig. 5), we assume that absorbing dust or absorbing continental aerosol has switched the algorithm to a different branch.

![Fig. 4 Radiance reflectances along the transect Cuxhaven (left) to Helgoland (right) for the top of atmosphere (RL_toa), path radiance (RL_path, computed with the breadboard), water leaving radiance (RLw_L2) and water leaving radiance determined with the breadboard processor (RLw_bread).](image)
Comparison between water leaving radiance reflectances: shipborne and derived from MERIS

The validation of the water leaving radiances along the Cuxhaven-Helgoland transect have been performed with above surface radiance measurements. Three TRIOS spectrometers have been used. One radiance meter pointed at the sea surface under a nadir angle of 35 degree, another at the sky with a zenith angle of 35 degree and an irradiance meter collected the downwelling irradiance. From these three measurements the water leaving radiance, RLw, has been computed using \( RLw = (Ls - ps \times Lsky) / Ed \), where Ls is the water surface radiance, Lsky the sky radiance, ps the specular reflectance of the sky radiance at the water surface and Ed the downwelling irradiance. The radiance meter pointing at the sea surface was mounted at the bow of the ship to view an undisturbed sea surface without ship induced foam. The difference between the viewing and sun azimuth was about 120-140 degree. Since this viewing geometry is different from that of MERIS one cannot expect identical spectra.

In Fig. 6 we show two of the spectra of July 29 at locations along the transect where water samples were taken. The figures show the water leaving radiance spectra as derived from MERIS with (1) the standard processor, (2) with the breadboard and (3) those derived from the above water reflectance measurements.

Most striking are the differences in the blue part of the spectrum. The RLw produced by the MERIS processor show much higher reflectance with an increase, which obviously is not correct. But also the breadboard spectrum is higher than that measured from the ship, which could be due to different viewing directions.

The corresponding data from August 14, but without breadboard results, show in most cases a good agreement for...
MERIS bands >4, but the same problem in the blue part of the spectrum. A possible explanation might be an error in the calculation of the path radiance produced by Rayleigh scattering.

Fig. 7 Spectra of the water leaving radiance reflectances at two stations of the transect Aug. 14, 2002. Left spectrum (a) of turbid water, right spectrum (b) of clearer water close to Helgoland

Input to the Neural Network

Consequence of the strange RLw of MERIS is that the neural network (NN) algorithm for the retrieval of water constituents is fed with spectra, which are out of training range. We have tested this with the NN processor for some of the spectra. The NN-processor consists of three NNs [2], the inverse NN produces the optical coefficients $bp$ (scattering by all particles), $agpb$ (absorption by gelbstoff plus by all particles after bleaching) and $apig$ (absorption by phytoplankton pigments). The forward NN computes the RLw from these properties and the third NN compares the measured RLw with the computed RLw. When the inverse NN is fed with a spectrum, which is out of range of the spectra used for training, an out-of-range flag will be switched on by the compare-NN. Nearly all MERIS spectra, which we have analysed, are out of training range. Fig. 8 gives two examples of the transect of July 29. They include the result of an alternative NN, which was used to test if MERIS band 9 could have produced some problems. Very obvious is the large deviation between MERIS RLw and the corresponding recomputed RLw spectrum. Due to the large deviation, which is true for all spectra, we cannot expect that the inverse NN produces correct results.

Fig. 8 Comparison between MERIS water leaving radiance reflectance (black line) and the corresponding spectra produced with the forward NN with input from the inverse NN (red, without band 9, and green line with all bands)

Comparison of derived concentrations

The last step of this preliminary validation was to compare the concentrations between the water sample and those computed with the NN. As said above, since the input to the NN is out of range, this comparison is of very limited value. Fig. 9a shows the concentrations of pigments expressed as chlorophyll $a$, of TSM scattering expressed as TSM dry weight and the absorption by gelbstoff plus bleached particles along the transect of July 29. Obvious are gaps at those locations, which are present in the RLw (s. Fig. 4). The general trends of TSM and $agpb$ show a decrease from Cuxhaven to Helgoland, which agrees with observations. However, the pigment concentration (pig2) is too high, while pig1, which is the chlorophyll concentration produced with the case 1 water algorithm, is in the expected range.
The concentrations along this transect were also computed with the breadboard processor (Fig. 9b), which uses the alternative atmospheric correction procedure, as described above, but the same NN for the retrieval of water constituents. The general trends for all three components are similar to that of Fig. 9a, but the absolute values are different. In particular, the pigment concentration is much lower and similar to that of the case 1 water algorithm (pig1).

Fig. 10 shows the results from MERIS processor, from the breadboard and the water samples for each of the three components. One has to keep in mind that the distribution of water constituents is very patchy in this area so that the mean value of a pixel with the size of 1 km² could be different from that of a 10 litre water sample.

\[
\text{mean value of a pixel with the size of 1 km² could be different from that of a 10 litre water sample.}
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\[
\text{Fig. 9 Concentrations along transect of July 29 as included in the MERIS L2 product (a, left) and produced with the breadboard processor (b, right)
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\[
\text{Fig. 10 Concentrations of (a) gelbstoff, (b) TSM (=SPM) and (c) chlorophyll along the transect of July 29. a_gelb_L2 is the L2 product (absorption x10), a_gelb_bread is gelbstoff agbp after atmospheric correction with the breadboard processor, a_gelb_sample is gelbstoff from water sample.
}
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\[
\text{spm_L2 is the L2 product of total suspended matter dry weight (TSM), spm_bread after atmospheric correction with the breadboard processor, spm_sample is TSM from water sample.
}
\]

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\text{pig*_L2 is the L2 product, algal_1 is derived with the case 1 water algorithm, pig2_L2 is the L2 chlorophyll product derived with the case 2 water NN, pig_bread is chlorophyll derived with the case 2 water NN after atmospheric correction using the breadboard processor and pig_sample is the chlorophyll concentration of the water sample using HPLC processing.
}
\]

Obviously, the gelbstoff/bleached TSM absorption (Fig. 10a) of the MERIS processor is much too low. This can be explained by the atmospheric correction, which produces too high reflectances in the blue part of the spectrum. But also the breadboard result is lower than the samples, probably for the same reason. The TSM values (Fig. 10b) of the MERIS processor are too high, but the breadboard results and water samples are in good agreement, at least for the first part of the transect. Fig. 10c shows all four pigment values, i.e. from the MERIS processor pig1 and pig2, from the breadboard pig_bread and the water sample pig_sample. Good agreement exists between case1 algorithm (pig1) and and
the breadboard (pig_bread) for the area close to Helgoland, where the water is more case 1 like. The MERIS case 2 values pig_2 are much too high, again as expected due to the wrong input into the NN.

The comparison between water samples and concentrations derived from MERIS for the transect of Aug. 14 are shown in Fig. 11. The TSM concentrations are in good agreement for the last part of the transect. The discrepancy in the first part may be due to the patchiness of this area. The gelbstoff absorption distribution shows the same shape as the water samples, but the absolute values are too low. The pigment concentration of algal_2 is too high compared to the samples and to the case 1 algorithm (algal_1), both of which are in good agreement in the central part of the transect.

![Concentrations of gelbstoff, TSM, and chlorophyll along transect of Aug 14.](image)

**Fig. 11** Concentrations of (a) gelbstoff, (b) TSM, and (c) chlorophyll along transect of Aug 14. Yellow triangles are data from water samples, blue lines are the level 2 product. In Fig. 11c the red line is algal_2 and the blue line is the algal_1 product of the case 1 algorithm.

**SUMMARY AND CONCLUSIONS**

Due to the fact that only two MERIS scenes were available for validation, and this shortly before the workshop, all results and conclusions are very preliminary.

At present, the biggest problem for the case 2 water products is the atmospheric correction in particular in the blue part of the spectrum, where abnormal spectra are computed. This has the consequence that the input to the NN algorithm is out of scope, i.e. out of the set of spectra used for training of the NN. The alternative atmospheric correction procedure, which is part of the GKSS breadboard processor, produces water leaving radiance reflectances, which are much closer to that determined by measurements from the ship. Also the concentrations are in better agreement with the ship measurements.

A problem for validation is the patchy structure of water constituents along the Cuxhaven - Helgoland transect. We expect that the match up can be approved significantly by using MERIS full resolution data. Furthermore, a statistical analysis of the FR pixels would provide us with information about the variance and thus about the degree of deviation, which we have to expect when we compare MERIS data with water samples. However, the comparison could also be improved by taking more water samples or by using a system with continuous flow instruments for absorption and scattering.

Another question is the detailed analysis of the influence of sun glint on MERIS data. This issue could be studied using scenes of two consecutive days, where, due to the orbit shift, MERIS views the same area with and without sun glint influence. Furthermore, the impact of different aerosols (marine and urban) and thin cirrus clouds on the quality of the atmospheric correction has to be investigated.

**ACKNOWLEDGEMENTS**

The cruises, the development of the breadboard processor and the validation work has been supported by a number of contracts and grants with ESA, EU (REVAMP, NAOC) and BMBF (MAPP, ENVOC). Furthermore, we thank the...
crews of RV "Heincke" and MS "Wappen von Hamburg" for their support.

REFERENCES