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FerryBox

From On-line Oceanographic Observations to Environmental Information

Report on the Use of Ferrybox Data for Validation Purposes of Satellite Data

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Document Reference Sheet

This document has been elaborated and issued by the European FerryBox Consortium.

P 1	GKSS	**GKSS Research Centre** **Institute for Coastal Research**	**Coordinator**
P 2	NERC.NOC	**NERC.NOC – National Oceanography Centre** **Southampton University and National Environment Res. Council** formerly NERC.SOC – Southampton Oceanography Centre	
P 3	NIOZ	**Royal Netherlands Institute of Sea Research**	
P 4	FIMR	**Finnish Institute of Marine Research**	
P 5	**HCMR** (formerly NCMR)	**Hellenic Centre for Marine Research** (formerly National Centre for Marine Research)	
P 6	NERC.POL	**Proudman Oceanographic Laboratory**	
P 7	NIVA	**Norwegian Institute for Water Research**	
P 8	HYDROMOD	**HYDROMOD Scientific Consulting**	
P 9	CTG **(formerly CIL)**	**Chelsea Technology Group** **(formerly Chelsea Instruments Ltd.)**	
P 10	IEO	**Spanish Institute of Oceanography**	
P 11	EMI	**Estonian Marine Institute** (in cooperation with the Estonian Maritime Academy)	

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1 Objectives

Most oceanographic observations do not cover temporal and spatial scales needed to run operational water quality models of coastal and shelf seas. Moreover, most monitoring programs have a limited set of observations in terms of parameters as well as a relatively low frequency. Research surveys are too expensive to be an alternative for operational and routine observations. Discrimination of natural from human impact on variability of the marine environment is impossible with the low sampling frequencies in ordinary monitoring programs or scientific surveys.

The problems indicated can be solved by using ships-of-opportunity such as ferries which cover regular routes with a high frequency, and thus offer the possibility of near surface measurements of a whole suite of parameters in an automatic way. These types of water quality measurements are important because they form the basis for the interpretation of the environmental quality and its development in coastal and shelf seas.

Satellite imagery is an increasingly important component in the identification of water quality. Ferrybox data also has the potential to contribute to the validation of satellite data because of its high measuring frequency in coastal and remote areas. The core sensor data from the FerryBox systems which all the FerryBox partners measure are: Chlorophyll-a fluorescence, turbidity, temperature and salinity. The first three parameters have analog satellite products as Chlorophyll-a (Chl-a), total suspended material (TSM) and sea surface temperature (SST), while the sea surface salinity (SSS) at the moment can not be measured from space.

In this report we give detailed comparisons of Ferrybox measurements with satellite data for 6 of the FerryBox systems and demonstrate the value of these data for satellite validation.

2 Scientific Aims

2.1 Motiviation

Using voluntary ships or “ships of opportunity” – SOOP could be an excellent method for collecting data and information to be used in connection with satellite data for both

- Scientific use for a 2D to a 3D information of the sea and
- Validation of the satellite data product.

In this study the focus is on the second point - how we can improve and validate the satellite data products. There are several possible improvements to a validation study if the method and sensor data from the Ferrybox systems can be used for such an approach.

The following points are important

- More validation data than compared with traditional validation
- Higher frequency of data from the same area
- Data from remote areas not routinely covered by research vessels
- Water samples can be triggered for events and during clear sky conditions
- Low cost validation data.

2.2 Objectives

One of the objectives for WP5 – “Application for FerryBox data” was to “explore the use of FerryBox data for validation of satellite data”. This has been done with focus on the optical satellite data products Chlorophyll-a, some examples of total suspended material and to a lesser extent the Sea Surface Temperature.

The optical Ferrybox sensor data need to be converted to the geophysical products that are processed with different coastal and open sea processing algorithms from the ocean colour signal measured by the satellite. This means that the Chlorophyll-a fluorescence data need to be converted to Chl-a, and the turbidity to TSM. Only the temperature can be compared directly, but since the satellite only measures the skin temperature the complexity of using a bulk temperature from the flow through of a FerryBox system taking the water from 4-6 meters needs to be considered. Some of the FerryBox systems have the possibility to collect discrete water samples from the flow-through system and from these samples the Chl-a and TSM can be analysed.

3 Satellite data

3.1 Product Description

In this study the MERIS sensor onboard the European satellite ENVISAT has been used for the optical ocean colour products and the AVHRR Sea Surface Temperature (SST) for the sea temperature. In addition some MODIS Terra Chl-a products were supplied by FIMR and these have been used as examples from the Baltic Sea.

3.1.1 MERIS Data Products

The MERIS instrument is composed of 5 cameras, each equipped with its own CCD sensor. MERIS provides quality data imaged at a nominal spatial resolution of 0.3 km in 15 spectral bands ranging in wavelength from 400 nm to 900 nm. The data used in this study are the "Reduced Resolution" data of 1.2 km. The MERIS-processing of water pixels is intended to provide the following Level 2 products:

Quantitative Geophysical Products

Directional water-leaving reflectance at bands 412.5, 442.5, 490, 510, 560, 620, 665, 681.25, 705, 753, 775, 865 and 885 nm; Chlorophyll-a (Chl-a) or algal pigment index 1 (Algal_1), algal pigment index 2 (Algal_2), total suspended material (TSM), yellow substance absorption at 442.5 nm (YSBPA), and photosynthetically available radiation (PAR). In addition there is one non-standard product based on the fluorescence feature of Chl-a called Fluorescence Line Height (FLH).

- **Chl-a:** There are two algal pigment indices, algal_1 and algal_2 for optically Case 1 and Case II waters respectively. Algal_1 is calculated from the ocean colour with a band ratio algorithm and is valid for oceanic water; algal_2 is determined from the ocean colour using a neural network (Doerffer and Schiller, 2000) and is valid for coastal waters where sediment particles and yellow substance might be present. Algal_2 is based on a scaling factor of the quantity apig at 442.5 nm.
- **TSM:** Is determined using a neural network. The product assumes a linear correlation between the content of particles and their properties for scattering of light based on the quantity bp at 440 nm.
- **YSBPA:** Similar to algal_2 and TSM, yellow substance is calculated using a neural net. The definition of yellow substance for MERIS is the sum of the coloured dissolved organics material (CDOM or YS) and the bleached particle absorption (BPA) at 442.5.
- **PAR:** This is a calculation of the photosynthetic available radiation (400-700 nm) from the MERIS band.
- **FLH:** This non-standard products is based on the capability of MERIS to measure the Chl-a fluorescence signal using the band 681.25 nm and reference bands (705, 665 nm).

Qualitative Products

(i.e., flags indicating the presence of the following):

Turbid Case II water; yellow substance-loaded Case II water; water with excessive scattering; continental absorbing aerosol; dust absorbing aerosol; as well as flags relevant to the quality of all products.

3.1.2 MODIS Data Products

Some MODIS Chl-a data product are used in the study of the Baltic Sea and are based on data from the MODIS Terra sensor. MODIS provides reflectance data with 14 spectral bands with nominal spatial resolution 1 km^2 ranging from 412 nm to 940 nm.

MODIS Terra was received daily from FIM/Sodankylä and this MODIS product is developed by using multivariate calibration against *in-situ* data from the Baltic Sea, and a preliminary local algorithm was developed for Chlorophyll mapping. The *in-situ* data has been collected from the Ferrybox systems of the area.

3.1.3 AVHRR Sea Surface Temperature

Radiometers measure the skin temperature, corresponding to the temperature of the first few microns of the ocean surface. The NOAA/AVHRR has three IR channels: channel 3 (3.6-3.8 micron), channel 4 (10.2-11.2 micron) and channel 5 (11.5-12.5 micron) which provide IR data at 1-km spatial resolution at the satellite subpoint (Kidwell, 1997). NOAA-14 and NOAA-16 have similar characteristics, but with distinct radiometer filter functions that require different algorithms. SSTs are derived from the 11 and 12 micron brightness temperatures (T11 and T12) using a set of coefficients derived from multi-linear regression on a database made of night-time *in-situ* measurements. The operational algorithms used are the split window non linear algorithms derived from SAFREE.

3.2 Processing of Satellite Data

3.2.1 MERIS Data

NIVA has, as a partner of the VAMP project and the validation activities for MAVT (AO609), access to MERIS data in real time and on request. In this project MERIS data has been downloaded for the different regions covered by Ferrybox systems within the FerryBox project. This has been done since spring 2005 and the data stored at NIVA. The data was made available to the partners from NIVA through this VAMP-project (Prodex contract. In this report a selection of data has been made on the basis of available *in-situ* Ferrybox data from the partners.

NIVA has received both Chl-a fluorescence data and Chl-a data which has been compared with Chlorophyll-a data products from MERIS. Two kinds of Chlorophyll-data from the partners have been used: Chlorophyll fluorescence from continuous transects and Chlorophyll content determined from water samples. For all data the corresponding position and time are given which are used when data are extracted from the MERIS scenes. MERIS scenes from the same day as the field measurements are preferred, but for the longer routes (FIMR, NERC.NOC), or night measurements plus/minus 1 day is included (GKSS, HCMR). Also data where both night and day fluorescence are available are studied (NIVA).

MERIS provides two Chlorophyll-a products, algal_1 and algal_2 for optical Case I and Case II waters respectively. Both MERIS products have flags which are raised by the processor in case of dubious data quality. The MERIS scenes used are generated with the currently official processor (IPF 4.06). This is used for 2004 and 2005 data and in addition some Skagerrak data from 2003 and 2004 are based on the validation database made available for the MAVT team in 2004. Currently a new version of the processor is implemented with a major change in the algal_2 product. This is a result of a new training of the neural network and this second reprocessing started in autumn 2005. The training data for this is also based on data from the Norwegian validation team and the new algal_2 product is very close to the Norwegian processing. Therefore for some of the data in the comparison studies this processing is used (Sørensen et.al. 2006)). A comparison has also been done for the Skagerrak area with a processing based on the REVAMP algorithm that was developed for the North Sea (Peters *et al*., 2005).

MERIS data have been extracted with the beam software package (VISAT) from Brockman Consult (www.brockmann-consult.de). For the water sample data the pixel corresponding to the sampling position has been used; for the transect data all pixels crossed or touched by the transect-line are extracted. The extracted data are presented either as the MERIS products as a function of *in vitro* Chlorophyll-a, or MERIS products and *in-situ* Chlorophyll-a fluorescence as functions of latitude or longitude.

When analysing the data we have seen that in practically all pixels extracted the algal quality flag is unfortunately raised. During the official MERIS validation it is observed that quality flags often are falsely raised (however, the opposite is not the case). In the present study possible reasons behind why the flag is raised are not investigated; instead all data are used regardless of quality flags raised.

3.2.2 MODIS Data

MODIS Terra L1b data was received daily from FIM/Sodankylä station through FTP. These MODIS products are developed by using multivariate calibration against *in-situ* data from the Baltic Sea. Multivariate calibration was applied to validate MODIS satellite data against automated flow through fluorescence records of Chlorophyll-a measured on board the ferry 'Finnpartner' along its regular route from Travemünde to Helsinki (Alg@line data, see, for example, http://www.fimr.fi/en/palvelut/levatiedotus.html). The Chlorophyll-a recording had a nominal spatial resolution of about 250 m. The fluorescence records were validated against Chlorophyll-a measurements analyzed from parallel water samples.

Partial Least Square regression analysis was used to develop a preliminary local algorithm for Chlorophyll mapping. Analysis showed that only the bands with the wavelengths from 531 to 905 nm (i.e. 531, 551, 667, 678, 748, 869, 905 nm) made a contribution to Chlorophyll-a variance. The atmospheric correction was made with the bands at 748nm, 869 and 905 nm.

3.2.3 AVHRR Data

The Ocean & Sea Ice Satellite Application Facility (O&SI SAF) is producing on a preoperational basis a range of air-sea interface products, amongst which Sea Surface Temperatures (SST). SST products are available within 2 hours after the last satellite data acquisition over the grids NAR (North Atlantic Regional), LML (Low and Mid Latitudes and MAP (Merged Atlantic Products). The NAR grid is divided in six areas at 2 km resolution. The MNOR area covers most of the Irish Sea, which is completely included in the GASC area. NAR products are derived from NOAA polar orbiter data and are provided every 6 hours at 02h00, 10h00, 12h00 and 20h00, central times of each mosaic.

As orbits are 102 minutes apart, the time difference between data in a same mosaic can be slightly larger than 200 minutes. The O&SI SAF SST accuracy is monitored at the hourly level through statistics applied using a match-up data base (MDB) which is built in real time from *in-situ* data and satellite estimates, according to a number of rules. Calculations of confidence levels are performed in real time. The SAF SST information is provided together with the exact time of each data pixel and the quality indexes resulting from the retrieval, validation, and quality control process. [Information extracted from: Ocean & Sea Ice SAF North Atlantic Regional Sea Surface Temperature Product Manual Version 1.1 November 2001 Alain Brisson, Pierre Le Borgne, Anne Marsouin Meteo-France/DP/CMS, 22302 Lannion, France].

3.3 Validation Methods and Strategies

The MERIS validation protocol is based on experiences from earlier validation campaigns from e.g. SeaWIFS with improvements specific for the MERIS sensor (Doerffer, R., 2002). Three strategies for MERIS validation are of interest in the protocol:

- Sampling and measurements during a MERIS overflight. Sampling should coincide with the pass within ±1 hour in Case I water, within ±0.5 hour in Case II waters.
- Comparison of parameters of the frequency distributions of concentrations derived from MERIS data and *in-situ* sampling during the same period.
- Comparison of long time series derived from *in-situ* and MERIS observations.

For the validation of water products samples should be taken from the zone which is optically significant and which is no deeper than approximately one half Secchi Disc Depth. In principle the water should be well-mixed. It is recommended to take several samples to establish that the water properties are homogeneous. One should measure sufficiently far from land to avoid the influence of land reflectance (> 5 km). The solar zenith angle at the time of MERIS overpass should be < 60 °. There are also weather requirements for radiance measurements like clear sky and low aerosol content to be considered and weather conditions should be recorded during field campaigns.

Validation using *in-situ* optical devices like a radiance instrument is further discussed in Doerffer (2002). Validation of the geophysical products from water samples should also follow the recommendation in the protocols and for the two parameters that we will consider here, namely Chl-a and to some extent TSM. In general the water samples should be filtered as soon as possible.

- For Chl-a the protocols recommend using glassfiber filter type GFF with immediate freezing. The extraction should be complete and HPLC methods for the analytical determination are recommended, but spectrophotometric determination is considered due to the large amount of data required for such a method. The fluorometric method is however not recommended.
- For TSM the same type of filters as for Chl-a should be used with a pre-washing of the filters, ignite at 450-480 °C, and soak in distilled water before drying at 75 °C for 1 hour and weighing after cooling. When preparing the samples the rinsing of the filter with 3*50 ml and separate rinsing of the filter rim is necessary.

The methods for yellow substance including the pigments analysed with the bleached filter pad method can be found in references in Doerffer (2002).

Validation of Sea Surface Temperature must be done with proper instrumentation like the SISTeR (Scanning Infrared Sea surface Radiometer) which is a self-calibrating filter radiometer capable of measuring brightness temperatures to 20 mK and skin SSTs to 0.3 K (Nightingale, pers. com). Using temperature from below the surface will give errors and differences that need to be analysed.

The ferry instruments used in the SST comparison were immersed in a tank situated in the ship's engine room which was fed with water from the engine's cooling system, intake at 3.5 m below the surface, at a rate to flush the tank every 30 s. A comparison between the ferry and a fixed buoy with a sensor 1 m below the surface, showed a mean difference of 0.11 deg C (ferry warmer) with a standard deviation of 0.65^{o}C from a comparison of 2599 values within 1 km and 20 minutes over 2 years. Hence SST measured by the ferry is close to that at 1m depth, probably because of the fairly high flow rate. This needs to be considered in the analysis.

4 Relations between Satellite Products and Ferrybox Data

4.1 Chlorophyll-a Fluorescence and Chlorophyll-a.

Chlorophyll-a fluorescence measured *in vivo* or *in-situ* are strongly coupled to the biochemistry of the phytoplankton and diurnal as well as seasonal variation is frequently seen. Therefore the use of a Ferrybox measured Chlorophyll-a fluorescence must take into consideration this variation when used for validation of the geophysical satellite products.

In the FerryBox project's Work Package 4 this has been investigated by comparing Chlorophyll-a from water samples with the Chl-a fluorescence from the Ferrybox sensor. For some areas as in the Skagerrak where the ferry covers the same track both night and day the variation in the Chl-a fluorescence/Chlorophyll-a ratio (Chl-a_Fl/Chl-a) could vary with a factor 2. For other areas such variation was not seen, but the seasonal variation was more predominant. Nevertheless this variation needs to be considered when Chl-a fluorescence data are to be used for validation of the geophysical satellite Chl-a product.

4.1.1 Calibration of Chl-a Fluorescence Sensors

The factory calibration of the sensor does not always follow the same procedure for all types of sensors and a separate field or laboratory calibration is needed for each sensor. The calibration should be converted to an extracted (*in vitro*) concentration of Chl-a. NIVA performed (in 2003 and 2004) a calibration of the Seapoint Chl-a fluorescence sensor used on the vessel "Color Festival" based on water samples collected during several transects and analysed by HPLC pigment methods.

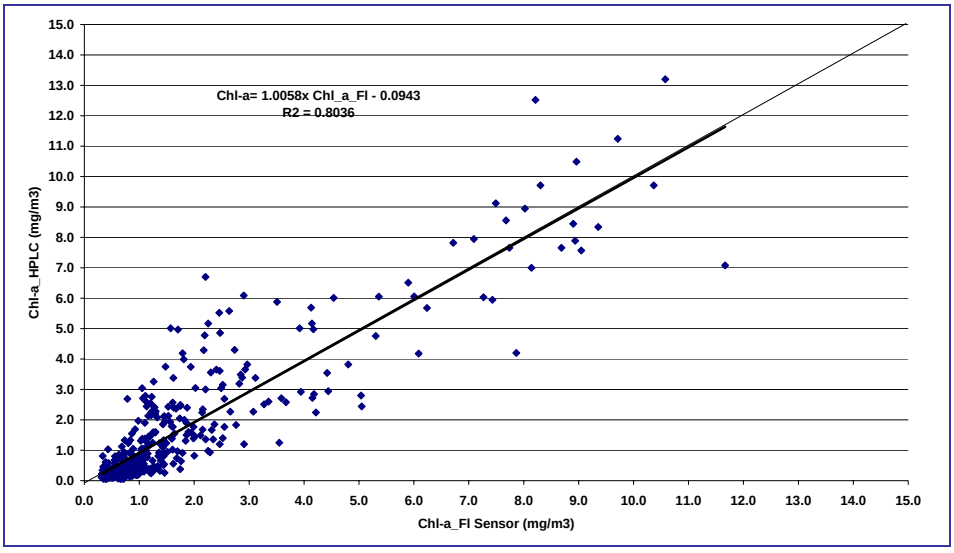

Figure 4-1: The correlation between Chlorophyll-a fluorescence (Chl-a_Fl) and Chlorophyll-a determined by HPLC in the Skagerrak in 2004.

Figure 4-1 shows the calibration of Chl-a for 2004 in the concentration range 0-15 mg/m^3. The yearly calibration was close to 1 and the Chl-a_Fl (Ferry) was explained by Chl-a_HPLC by 80%. The data covers the period from January to December and the variation observed, e.g. around 1.5-3 mg/m^3 Chl-a_HPLC, occurs during the spring bloom period.

4.1.2 Accuracy of the Chl-a Fluorescence

When the overall Chl-a_Fl data are related to an *in vitro* concentration of Chl-a the first step in the use of the sensor data is established. The deviation during the year 2004 between the "calibrated" Chl-a_Fl and *in vitro* Chl-a is seen in Figure 4-2 for the Skagerrak. Highest deviation is seen during the spring bloom in February to April with the largest negative deviation in March. The difference for the four last month of the year is investigated, but is most likely due the changes in phyto-plankton composition. Such variability must be considered in order to improve the accuracy in converting the Chl-a_Fl to Chl-a before the derived Chl-a from the sensor data are used to compare with the satellite products. Such a system of comparing Chl-a_Fl and Chl-a based on water samples also gives a good quality assurance of the data.

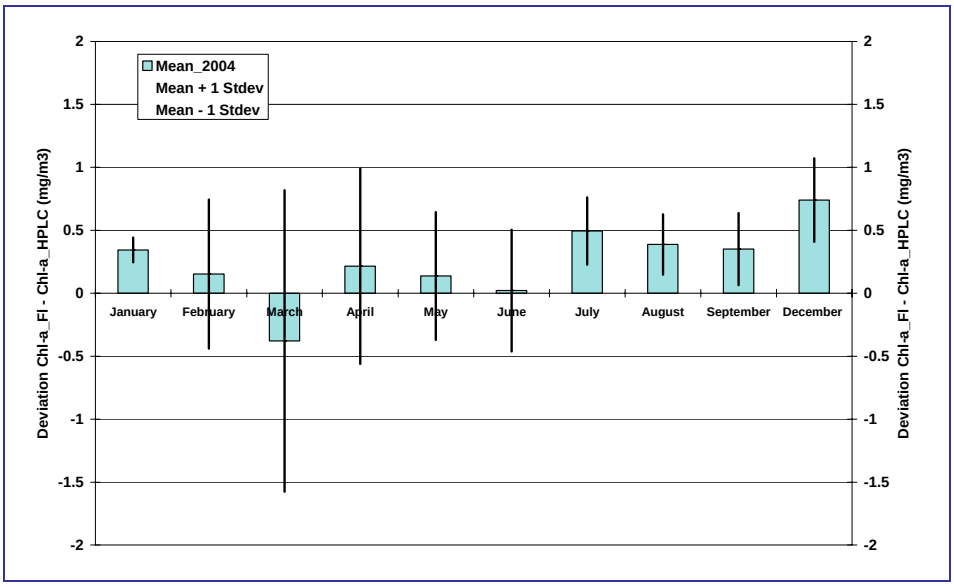

Figure 4-2: Accuracy of the Chl-a fluorescence related to the Chl-a during one year (2004) of measurements in the Skagerrak.

4.1.3 Use of HPLC and Spectrophotometric Analysis of Chl-a

The MERIS protocols recommend the HPLC methods for Chl-a and all the *in-situ* data used for the training of the Neural Network for processing the Level 2 Algal_2 products of MERIS is based on such HPLC data. The differences of HPLC and spectrophotometric derived Chl-a may vary in natural waters and specially during a decaying algal bloom when the degradation of Chl-a is high. During such events the HPLC data will be lower than the spectrophotometric ones which do not discriminate between the degradation products as the HPLC method does. In Figure 4-3 an example of such a data set is shown. The data are from the Skagerrak area and were collected under the VAMP project for satellite validation (NIVA) (VAMP-Validation of MERIS Data Products, ESA Prodex Contract no. 14849/00/NL/Sfe(IC)).

The protocols allow for using spectrophotometric methods, but one should be aware of this variation. The data in the figure which deviate from the 1:1 line are from decaying phytoplankton after a bloom.

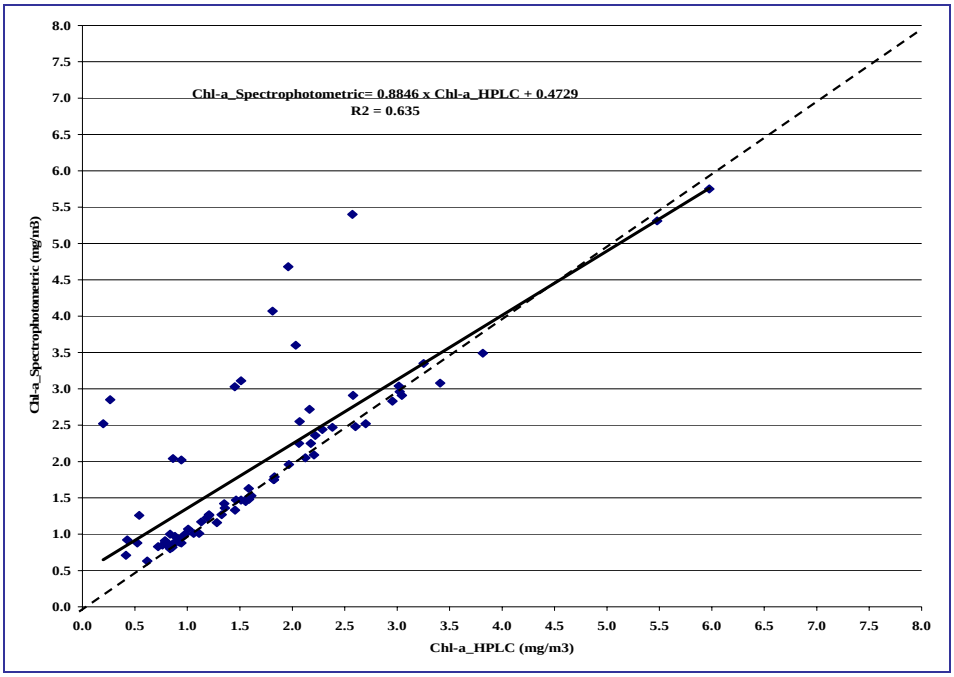

Figure 4-3: Correlation of HPLC and spectro-photometric analysis of Chl-a from a dataset in the Skagerrak 2003-2004 (data from the VAMP project, NIVA).

4.2 Turbidity and Total Suspended Material

4.2.1 Calibration of a Turbidity Sensor with In-situ Samples

The turbidity measured in the Ferrybox is based on a sensor measuring the scattered light in the red part of the spectrum and should be related to the ISO (7027) turbidity standard. Some sensors also use blue light (same as the excitation light for fluorescence) which can have another backscatter relative to the particles. The calibration of the sensor output to an ISO standard turbidity is needed for each of the sensor types also taking into account the effect of any micro air-bubbles that can be caused by pumping or air trapped in the Ferrybox system.

The ISO 7027 standard recommends use of a Formazine standard as the basic calibration and in addition one could use water samples for control. Such a control has been performed for the ‘Color Festival’ Ferrybox in the Skagerrak Sea during 2003 and 2004. Figure 4-4 shows the data for 2003 where the relationship shows good agreement between the sensor and the turbidity determined from the water samples in the laboratory. The data close to the coast has been omitted since they do not represent the water due to the small time differences between the sensor data and the collected water. In this area the water is highly dynamic and strong gradient over small distances.

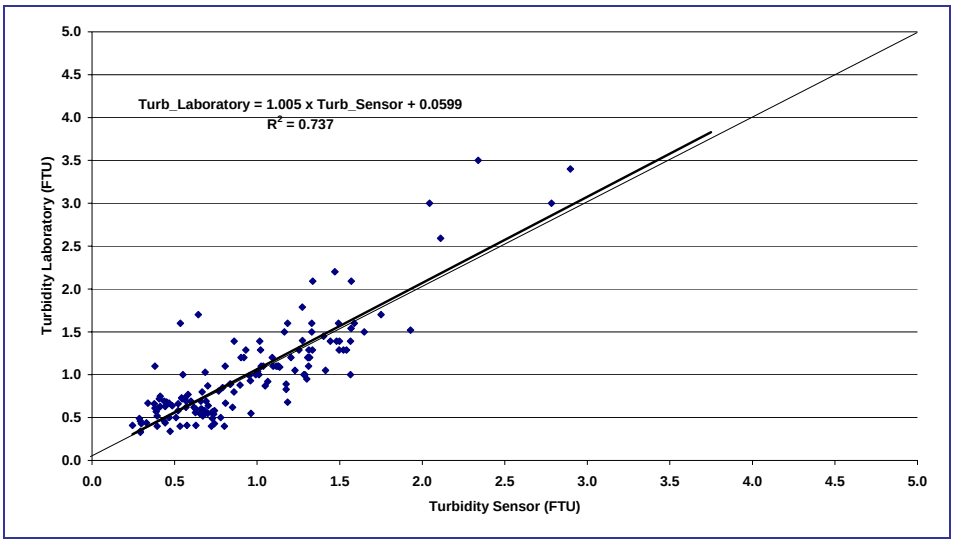

Figure 4-4: Calibration of a Seapoint Turbidity Sensor on the Ferrybox system in Skagerrak in 2003 with collected water samples and analysed in the laboratory.

4.2.2 Accuracy of the Turbidity Sensor

The accuracy of the turbidity signal from the sensor needs to be known if the turbidity is to be converted to TSM. Such a control of the accuracy is seen in Figure 4-5 for the Skagerrak area indicating that with a properly calibrated sensor where the bio-fouling is handled with self cleaning systems or wipers the accuracy is good. On a yearly basis the absolute accuracy is about ± 0.4 FTU.

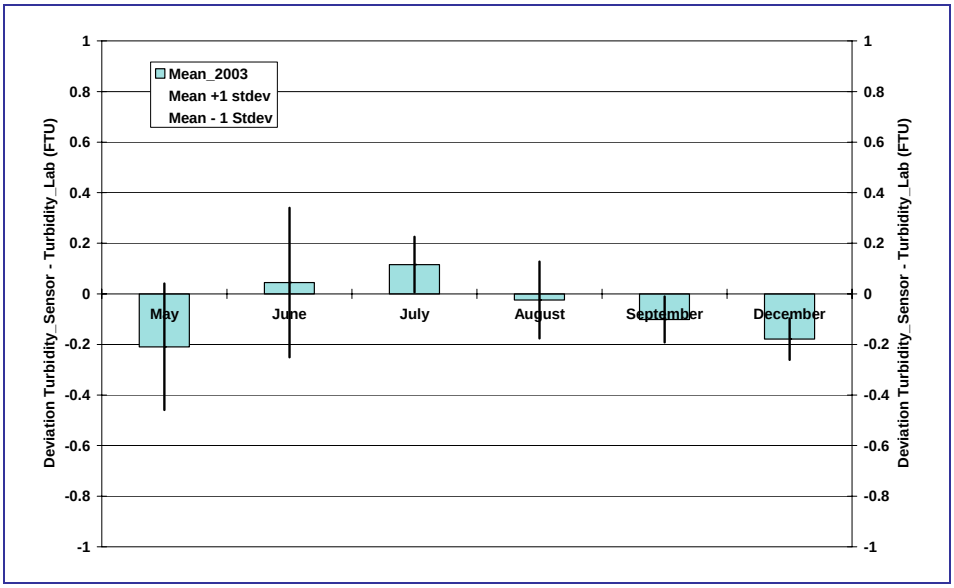

Figure 4-5: Deviation in the monthly mean concentration of turbidity between sensor and water samples for 2003 in the Skagerrak.

4.2.3 Relation between Turbidity and Total Suspended Material

When the sensor data are proper converted to a turbidity value in the correct unit (FNU, FTU) one can investigate if the turbidity/TSM ratio is "constant" for the region covered by the Ferrybox line. With an established turbidity/TSM relation one can calculate the TSM from the *in-situ* sensors. Such a preliminary comparison has been done on water samples collected from the Skagerrak and some other areas in the North Sea and UK waters.

In Figure 4-6 the data are shown with the relation for the Skagerrak area indicated. The data are scattered, but reasonable in agreement with the turbidity for the Skagerrak area, in the concentration range 0 – 15 g/m^3 The other areas that also can have concentrations up to 50 g/m^3 can have other relations and need to be investigated closer: Here we see that there is a tendency that the turbidity/TSM ratio is lower in these areas indicating less scattering material (more organic content).

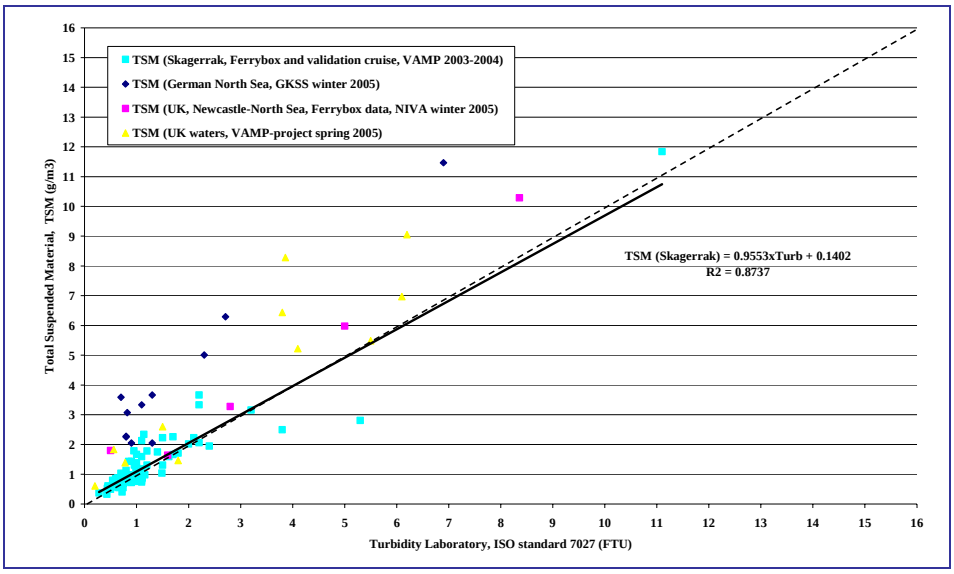

Figure 4-6: Relation between turbidity following the ISO 7927 standard and TSM measured according to the MERIS protocol.

4.3 Sea Surface Temperature (SST)

As far as we know, the validation of AVHRR SST with the Ferrybox-determined temperature has not been the subject of much investigation.

In general the skin temperature as measured by a remote sensor can sometimes be significantly higher in the few upper millimetres during warm and calm days. Comparison with a bulk temperature measured *in-situ* with a Ferrybox sensor is not directly comparable during such situation.

As mentioned in Section 3.2, the FerryBox measurements used here can be considered equivalent to 1m below the sea surface. In our reported comparisons we have only used the satellite measurements collected at night-time to try and reduce this skin temperature effect.

5 Inter-comparison of Chlorophyll-a Analysis

5.1 Background

Using *in-situ* Chlorophyll-a (Chl-a) data from different validation teams that use different methods can lead to wrong Chl-a data and to wrong assumptions about the quality of the satellite data.

The protocol for validation of Chl-a recommend use of HPLC methods and a proper extraction procedure: Use of spectrophotometric methods was allowed in the MAVT since many laboratories use spectrophotometry for their routine analysis, while fluorometric methods for *in vitro* determination of Chl-a were not recommended.

To explore this variability between the FerryBox partners a Chl-a intercomparison was arranged. Additional teams working on satellite validation, and teams who have participated in similar earlier exercises were invited to join. The inter-comparison was arranged in autumn 2005 by the FerryBox partner NIVA and a total of 13 laboratories participated.

The FerryBox partners that operate Chl-a fluorescence sensors – FIMR, NIVA, GKSS (2 laboratories), NERC.NOC, IEO and EMI – participated. The FerryBox partner NERC.POL was represented by the laboratory EPA, Ireland and in addition the following laboratories were included; SYKE in Finland, TARTU Laboratory in Estonia, PML in UK, and MUMM in Belgium. The participants represent 10 different countries.

Details about the laboratories and their methods are presented in Table 5-1 and included HPLC, fluorometric and spectrophotometric determination, and different extraction techniques and solvents (acetone, methanol and ethanol). In total, 15 results are reported, as two of the laboratories presented data from more than one analytical method.

5.2 Preparation of the Inter-comparison Samples

Samples of algal cultures were used and the procedures followed earlier tests performed in the MAVT-“MERIS MAVT and AVHRR validation Team” (Sørensen et. al. 2006). Samples A, B, C and D from algal cultures were prepared at the laboratory of NIVA. Samples A and B were a culture of a diatom which should be easy to extract, while samples C and D were of cyanobacteria which are more difficult to extract. The samples were filtered onto 47 mm GF/F Whatman filters. The filters were then transferred to vials and immediately frozen in liquid nitrogen, before storing at -80 °C until transportation to the participants.

During the sub-sampling for filtration, the samples were kept in the dark in a 50 L container under continuous stirring. Every 10th sample was used to control the variation due to filtration, handling and storing. These results are shown in Figure 5-1, with the average values and the standard deviation stated in the figure. The samples were transported to the participants in an iso-pore box of minimum 50 mm wall thickness and containing about 5 kg dry ice, which was sufficient to keep the samples deep-frozen for 3 to 4 days.

The variation due to the filtration, filter handling and the errors associated in the analytical procedures when one laboratory analysed the filters was 5 and 9 % for samples A and B respectively and 13 and 15 % for samples C and D.

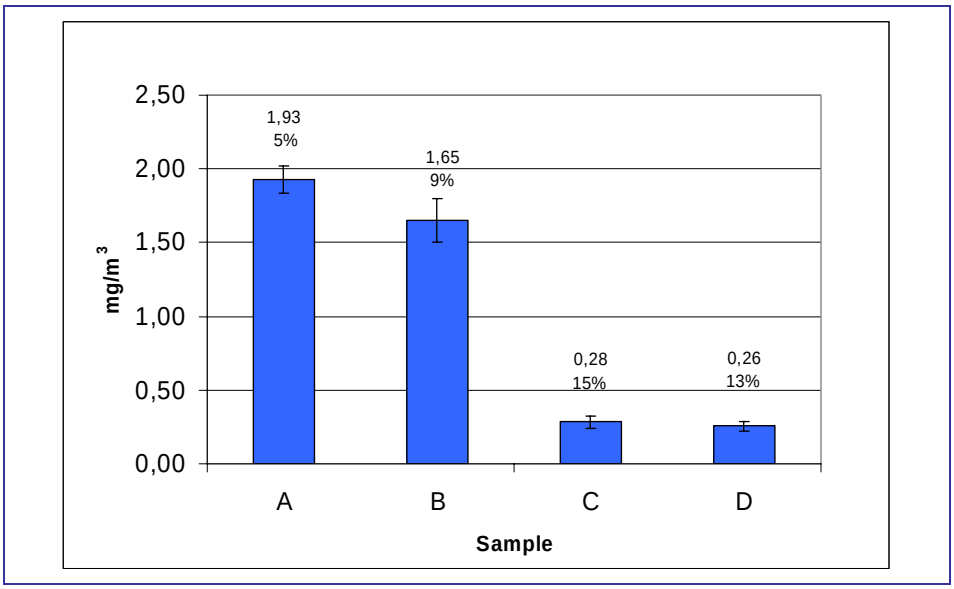

Figure 5-1: Control of the variation of samples during filtration of the algal culture. Mean ±1 standard deviation.

5.3 Extraction of Pigments

The extraction of pigments was performed in different ways by the laboratories. The solvent used was most often acetone or acetone : water (9:1) or ethanol, but also methanol was used. An overview of the extraction techniques and methods is summarised in Table 5-1 Chlorophyll-a was analysed by either spectrophotometric (6 results), fluorimetric (4 results) or HPLC methods (5 results). Two laboratories used two different methods.

Table 5-1: Institutions, extraction methods and analysis methods employed by the participants.

			Extraction				Analysis		
Number	Institution	Country	Solvent	temperature °C	sonication time	soaking time	Spectro-photometer	Fluore-scence	HPLC
1	EMI	Estonia	96% EtOH	20		24 h	x		
2	FIMR	Finland	96% EtOH	20		18-24 h		x	
3	IEO	Spain	90% acetone	4		24 h		x	
4	SYKE	Finland	90% EtOH	75		5 m	x		
5	NOC	UK	acetone	30	30 s		x	x	
6	NIVA	Norway	90% acetone	20	1 m	4 h	x		x
7	EPA	Ireland	96% MeOH	70	1 m	1 h	x		
8	GKSS Büsum	Germany	acetone	4		35 m			x
9	GKSS Hamburg	Germany	acetone	-40		24 h			x
10	HCMR	Greece	90% acetone	20				x	
11	PML	UK	acetone	20	35 s				x
12	MUMM	Belgium	90% acetone	20					x
13	Tartu	Estonia	96% EtOH	20		1 h	x		

The table shows also that in addition to the analytical determination there were three different extraction solvents, extraction temperatures ranged from 40 to 70 °C and from 5 minutes to 24 hours in extraction time. The variation in methods is therefore large and the use of different solvents and determination steps is probably causing most of the variation in the results.

5.4 Results

5.4.1 Comparisons between the Participants

The participants measured two pairs of water samples with Chlorophyll-a concentrations ranging from 0.2 to 2 mg/m^3. The results for all participants are shown in Figure 5-2 for the four samples measured. Each sample is presented twice. In the left column, the results are ranked after laboratory number, whereas in the right column the results are ranked after the value measured. In the figures, the green line signifies the median value in the results set. The red lines are the median value ± one standard deviation of all the results in the dataset.

For samples A and B, the value ranked figures show that very few laboratories are outside the median ± 1 standard deviation, which must be considered to be quite satisfactory. The overall variation between the participants, calculated as the standard deviation relative to the median value, was 18% and 13% for sample A and B respectively.

For samples C and D, which were more difficult to extract and contained much less Chlorophyll-a than samples A and B, the results varied more among the participants as can be seen from Figure 5-2. Still, there are relatively few laboratories outside the median ± 1 standard deviation, but the numbers for the overall variation among the results are higher for these two samples. The variation was 44% and 39% for samples C and D respectively. The effect of extraction is clearly seen in this figure since the extraction with alcohol has generally higher values than the acetone extraction.

Another general observation for all the samples is that the HPLC results are lower than the spectrophotometric results except for one laboratory, while the fluorescence results have greater variation even with the same extraction solvent.

5.4.2 Comparison of extraction Solvent and Methods

At NIVA, extraction of samples A-D by three different solvents was performed. The extracts were analysed by both HPLC and spectrophotometer, and the results are given in Figure 5-3. From this, it is evident that the solvent plays an important role in how much Chlorophyll-a is extracted from of the algae on the filter. It is most evident in samples C and D which consist of Cyanobacteria, where acetone evidently is less efficient than methanol and ethanol in extracting the pigments. The median value between the samples was 0.56 and 0.51 mg/m^3 respectively. The overall variation between samples was 32 % and 43 % respectively.

For samples A and B, acetone had the same extraction efficiency as the alcohols. An overall observation for this experiment is that HPLC results are lower than spectrophotometric results. For samples A and B the median values were 1.84 and 1.65 mg/m^3, and the variation was 15 % and 13 % respectively. In Figure 5-4 there is a comparison between the median values obtained by the participants compared to the analysis performed by one laboratory using different methods. The standard deviation is given as error bars in the figure. This shows that almost all of the variation observed between the participants can be explained by the use of different extraction methods and different methods of analysis.

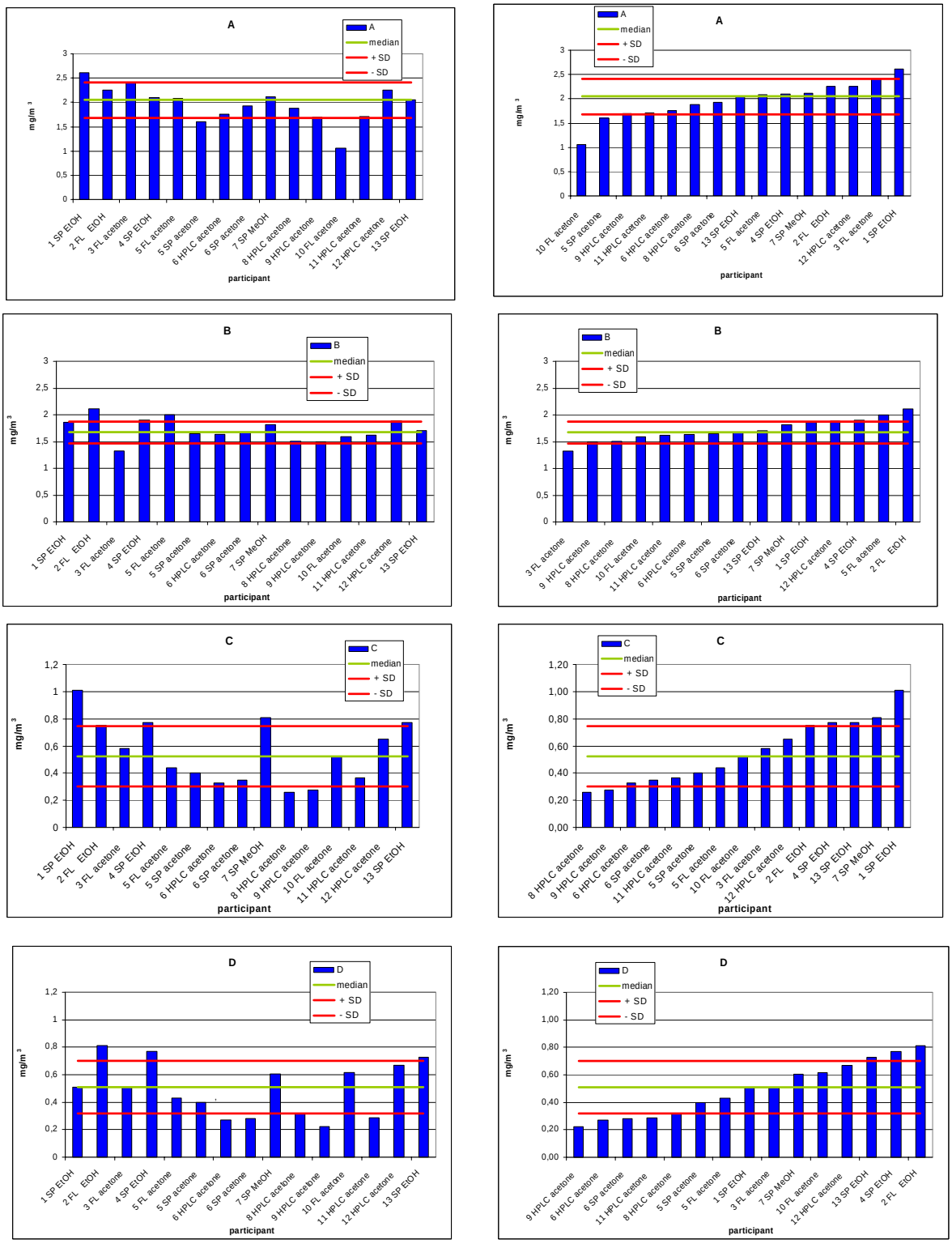

Figure 5-2: Results for all participants ranked after lab number (left), and after measured value (right). The green line represents the median value and the red lines the ± 1 standard deviation.

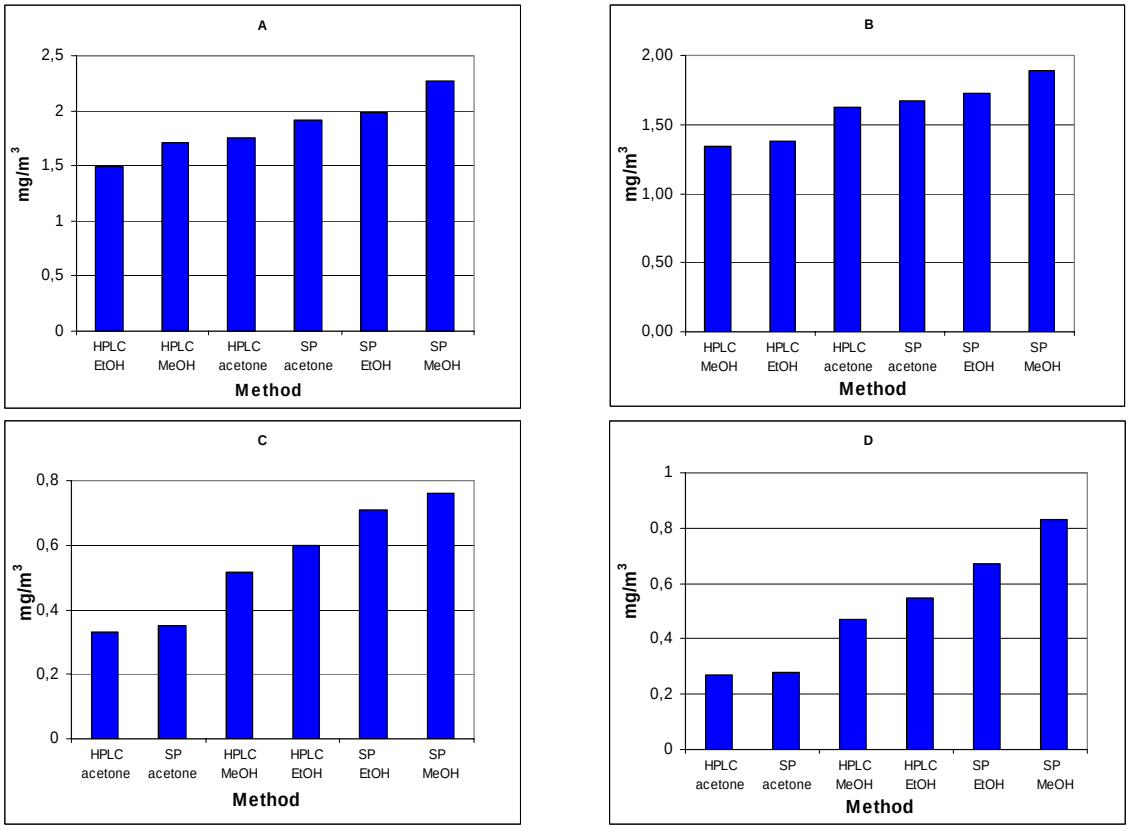

Figure 5-3: Extraction with different solvents and analysis of samples A-D with HPLC and spectrophotometer at one laboratory (NIVA).

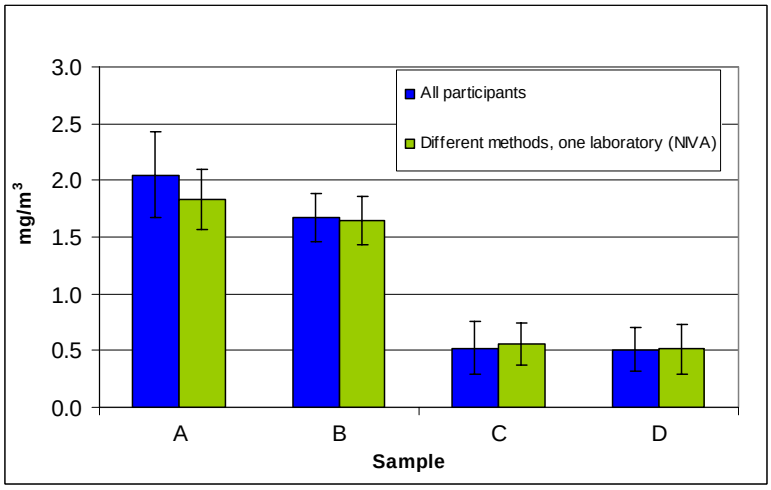

Figure 5-4: Comparison of median values obtained by participants and the different methods used by one laboratory (NIVA). The error bar represents ± 1 standard deviation.

5.4.3 The Overall Error Estimate in Chl-a Determination

The results from the 4 samples A, B, C and D can be presented as the sample pair AB and CD since they have approximately the same concentration and same type of alga. Following the principle of the Youden (see Sørensen et.al. 2006). The results expressed in a Youden are illustrated in Figure 5-5. Every point with a number is the result of the participants for the respective sample pair. The sample pair AB with the easily extratcable diatom have most of the laboratories within 20% of the median value. Results that fall along the line in the upper right or lower left quadrant have systematically too high or low values, while laboratories in the two other quadrant are influenced by random errors. We see from this figure that laboratories 10, 3 and maybe 1 have random errors in their analytical procedures.

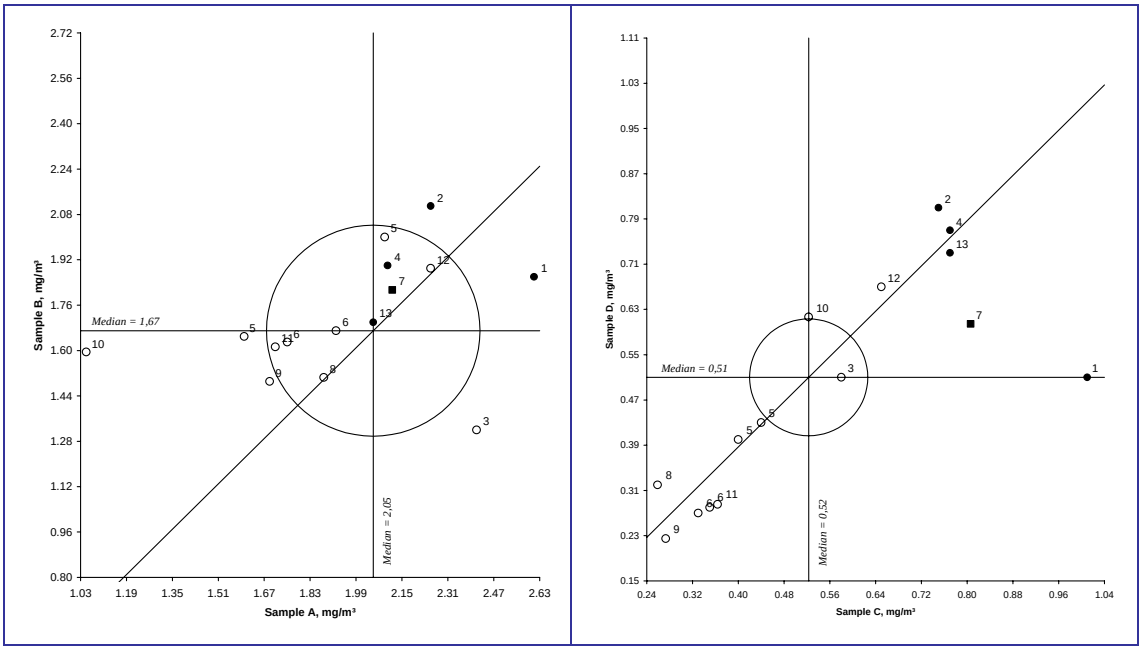

Figure 5-5: Results from the samples pair AB (left) and CD (right) for all the participants. Open circles are laboratories using acetone extraction, filled circle ethanol and filled quadrant methanol. The circle represents 20% of the median value..

The result for sample pair CD illustrates the effect on the extraction solvent on alga that are more difficult to extract like the Cyanobacteria used here. This shows very clearly the importance of using alcohol for extracting Cyanobacteria, the algal population that often occurs e.g. in the Baltic Sea.

If we assume that the team used the optimal extraction procedures for their type and dominating phytoplankton we can assume that the left figure better resolves the expected error for the partners. Except for 2 to 3 laboratories the participants are close 20% of the true median values.

6 Validation of MERIS Chlorophyll-a Products

6.1 Comparisons in the Baltic Sea

The FerryBox systems operating in the Baltic Sea are: FIMR Ferrybox operating from Travemünde to Helsinki and the EMI Ferrybox line between Tallin and Helsinki. The FIMR line departs the evening of one day, crosses the central Baltic, and arrives in the harbour on the morning of the next day. The EMI route has several daytime passes. The Baltic Sea is very complex with high and variable phytoplankton biomass and is optically a Case II water type. Earlier satellite remote sensing data from the area as e.g. the SeaWIFS sensor have shown much too high Chl-a values, and the area is known as problematic for standard satellite data products.

Data from both lines was available in summer 2005 during and after a Cyanobacteria bloom. On 10th July 2005 MERIS data was available as well as water samples of Chl-a analysed by the two partners. Figure 6-1 shows an RGB image from this situation with the ferry lines and sampling points where Chlorophyll-a was collected. The Cyanobacteria bloom in July 2005 in the open sea area was dominated by *Nodularia Spumigena* which constituted about 90 % of the total biomass.

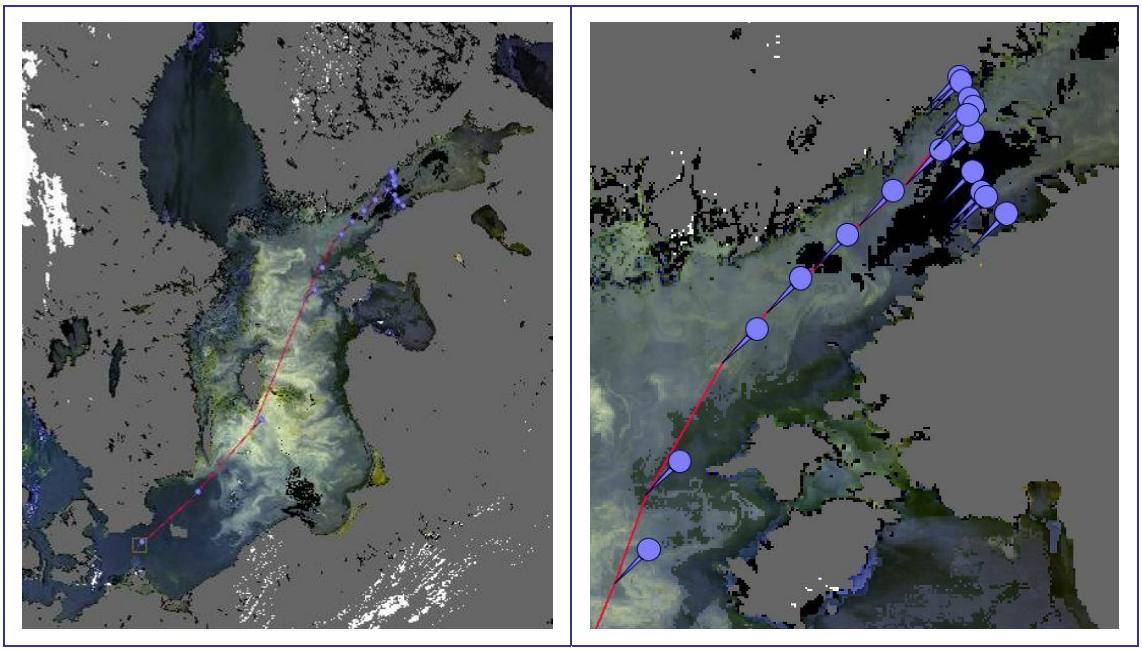

Figure 6-1: An MERIS RGB image from 10 July 2005 with the Ferrybox routes and sampling stations for the FIMR and EMI route.

The RGB image shows clearly the complex surface patchiness of the bloom which makes a comparison with water samples very difficult. This horizontal patchiness in the surface is seen from the image, but in addition there is probably vertical patchiness which is also likely to occur during typical blooming situations. From a validation point of view this is an impossible area to validate products with any high precision since the algorithms assume vertical homogeneity in the water that contributes to the reflectance. Also the fact that the ferries collect water from below the surface layer will complicate the validation even more. Nevertheless, it is of interest to see whether the Ferrybox data fit to the satellite data.

In such a complex area it is important to inspect the marine reflectance (Figure 6-2) from a set of positions and at the control stations along the FIMR route. The spectra show the high absorption of pigments in the blue part of the spectrum as well as the absorption/reflectance peaks around the Chl-a absorption band at 665 nm. The reflectance around 560 nm is due to the Cyanobacteria pigments. This type of exceptional spectra has not been accounted for in the training of the new neural network for MERIS algal_2 products.

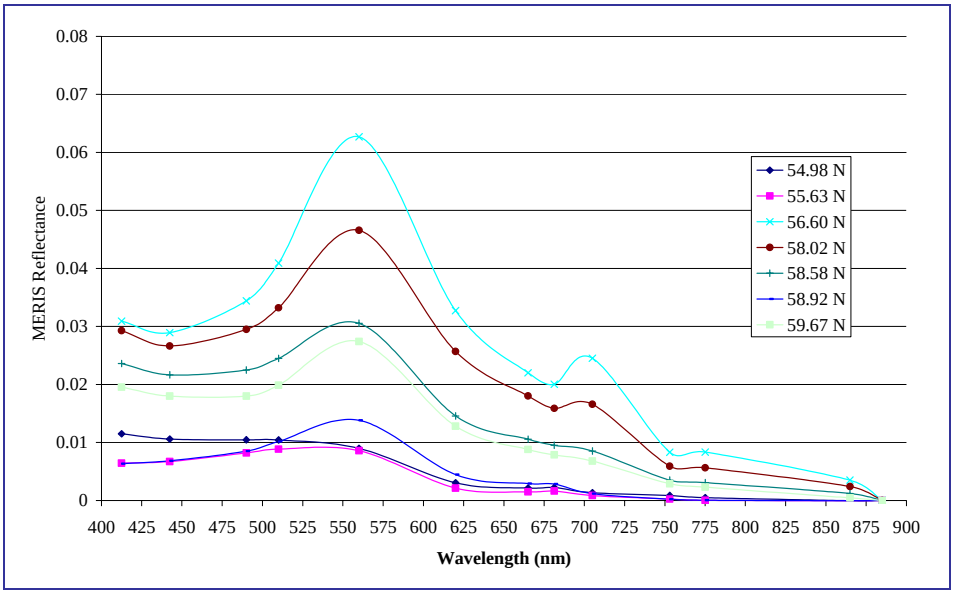

Figure 6-2: The MERIS reflectance on some positions along the ship track of the FIMR line on 10 July 2005 used for checking the quality of the MERIS data.

Table 6-1 below gives an overview of the stations along the track. The MERIS product at 3 stations close to Helsinki failed in processing the alga products, and in general the products flag was always raised.

Table 6-1: Overview of FIMR stations from 10. – 11. July 2005 with Chl-a and the results from the MERIS algal products.

Station	Date	Time (UTC)	Lat	Long	Chl a (mg/m^3)	MERIS Algal_1 (mg/m^3)	MERIS Algal_2 (mg/m^3)	Algal_2 NIVA processing (mg/m^3)	MERIS YS (m^{-1})	MERIS TSM (mg/m^3)
2005160265	10.07.2005	02:06	54.98	13.50	0.93	1.24	2.26	0.77	0.039	0.60
2005160266	10.07.2005	06:37	55.63	15.50	1.09	2.52	2.39	0.83	0.059	0.65
2005160267	10.07.2005	12:41	56.59	18.00	7.33	29.10	24.80	19.49	0.000	6.13
2005160269	10.07.2005	21:24	58.57	21.00	8.78	6.71	10.90	6.43	0.020	3.19
2005160270	10.07.2005	22:47	58.91	21.50	2.68	9.30	7.09	3.60	0.787	1.08
2005160271	11.07.2005	01:00	59.37	22.50	5.20	23.40	16.00	10.79	0.020	5.91
2005160272	11.07.2005	01:57	59.53	23.00	5.40	7.09	9.30	5.19	0.020	2.57
2005160273	11.07.2005	02:50	59.64	23.50	7.98	10.40	11.60	7.00	0.020	3.56

In Figure 6-3 a transect through the Cyanobacteria bloom on 10 July 2005 is shown. The Chl-a from the water samples show higher Chl-a than the Chl-a Fluorescence which is due to the low fluorescence efficiency of the Cyanobacteria compared to other areas with other algal groups. An effect of the day/night variation of Chl-a fluorescence must also be considered since it is daytime when the ferry is between 56-59 ° N.

The NIVA MERIS processing are in better agreement with the Chl-a fluorescence data in the southern part of the Baltic Sea where the *Nodularia Spumigena* is not so dominant. Here also the MERIS algal_2 products fit well with the Chl-a value. Also outside the intense bloom at 59 °N the MERIS data with the NIVA processing are in reasonable agreement with the water samples. Another complicating factor in such blooms is the vertical movement of the Cyanobacteria during night and daytime. The high scatter in the data is typical for such a bloom with filamentous horizontal distribution, and we do not know the vertical distribution in the water masses relative to the water intake of the ferry.

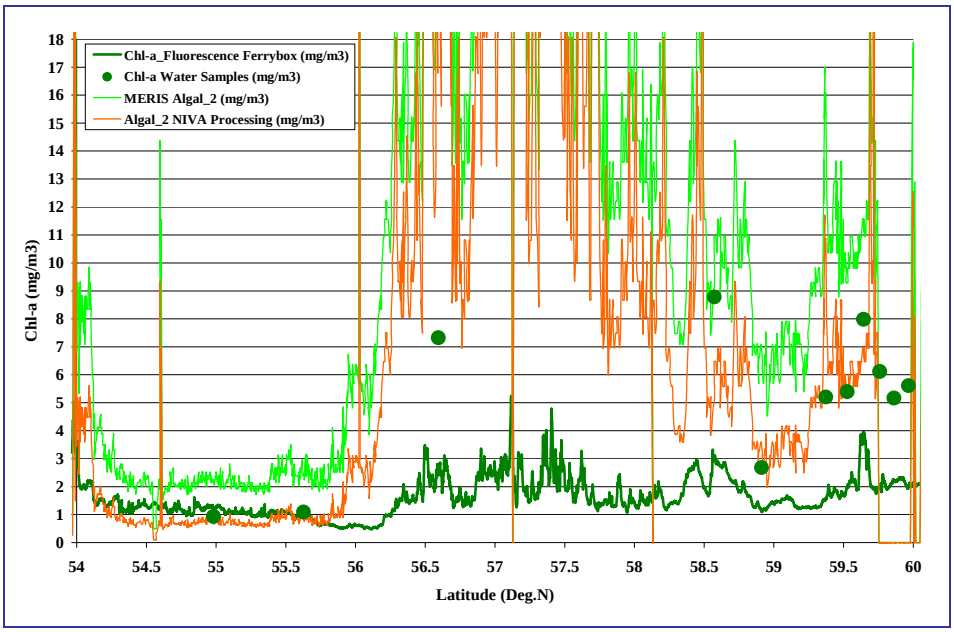

Figure 6-3: Transect of Chl-a products from the FerryBox and MERIS for the FIMR line on 10 July 2005 during a Cyanobacteria bloom.

In

Table 6-2 and Figure 6-4 the data from the same image on 10 July are compared with the in-situ data from EMI for the route between Tallinn and Helsinki. No report exists of a Cyanobacteria bloom in this area in July and the Chl-a is also much lower, but here standard processing as well as the new processing of algal_2 show higher values than the in-situ Chl-a data. This effect is not analysed in detail and as for the other part of the Baltic Sea the product flag was raised indicating a failure in the processing, but since the flag probably does not work either in this area it was of interest to compare the values. A closer study of the MERIS spectra should be done for the area.

Table 6-2: Chl-a from the EMI Ferrybox route compared to the MERIS products for 10 July 2005.

Station	Date	Time	Lat	Long	Chl a (mg/m^3)	MERIS Algal_1 (mg/m^3)	MERIS Algal_2 (mg/m^3)	Algal_2 NIVA Processing (mg/m^3)	MERIS YS (m^{-1})	MERIS TSM (mg/m^3)
WQ3	10.07.2005	18:54	60.119	24.905	5.10	26.1	14.4	9.3	0.020	1.49
WQ5	10.07.2005	19:15	60.032	24.906	5.16	5.4	10.4	6.0	0.020	2.22
WQ6	10.07.2005	19:25	59.992	24.902	4.26	8.8	12.9	8.1	0.020	3.31
WQ7	10.07.2005	19:54	59.882	24.801	4.65	11.6	14.4	9.3	0.020	2.57
WQ10	10.07.2005	21:09	59.588	24.673	2.02	1.4	3.9	1.6	0.059	1.44
WQ11	10.07.2005	21:38	59.482	24.765	1.59	3.9	8.3	4.5	0.020	1.55

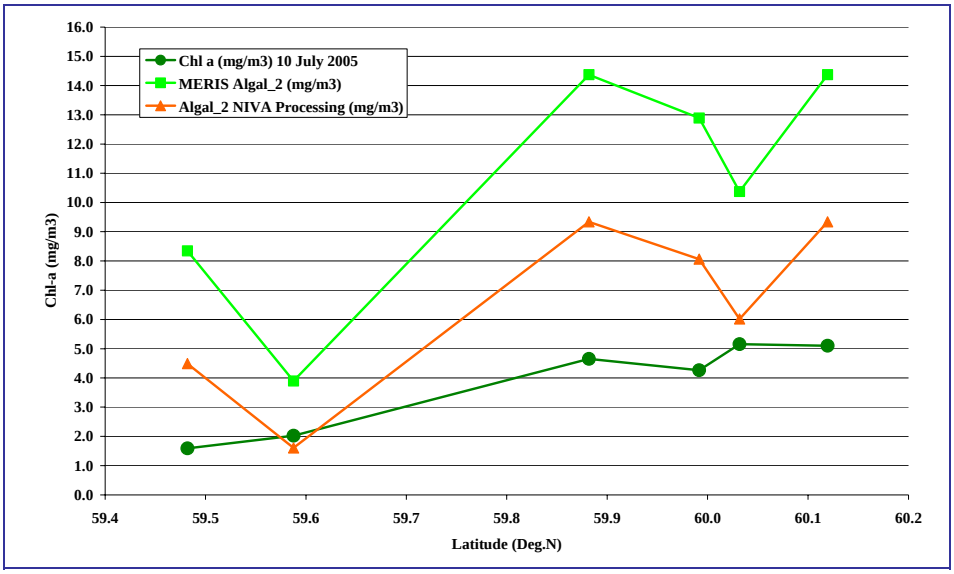

Figure 6-4: The transect between Tallinn and Helsinki on 10 July 2005 of the Chl-a data from EMI and the MERIS products.

After the algal bloom the MERIS algal_2 standard product is in better agreement with the *in-situ* data as shown for the FIMR water samples from 15th of August (Figure 6-5) for the southern part of the Baltic, while the northern part and in the Gulf of Finland it is too high. Also under this situation the quality flags are raised, so the comparison in absolute values can not be used quantitatively. Compared to the situation during the bloom in July (Figure 6-3) the results are now different.

The decay of the bloom at the end of July is seen from the the *in-situ* data in Figure 6-6 and from the MODIS Terra data examples in Figure 6-7. The MODIS data show high values in the central Baltic Sea for both of the July situations, while in August the values have decreased. This is also illustrated in the *in-situ* data, but the July Chl-a data is much lower than what the MODIS data shows. The MODIS data are calibrated with Ferrybox data from a depth of the water intake of the ferry and this can affect the results.

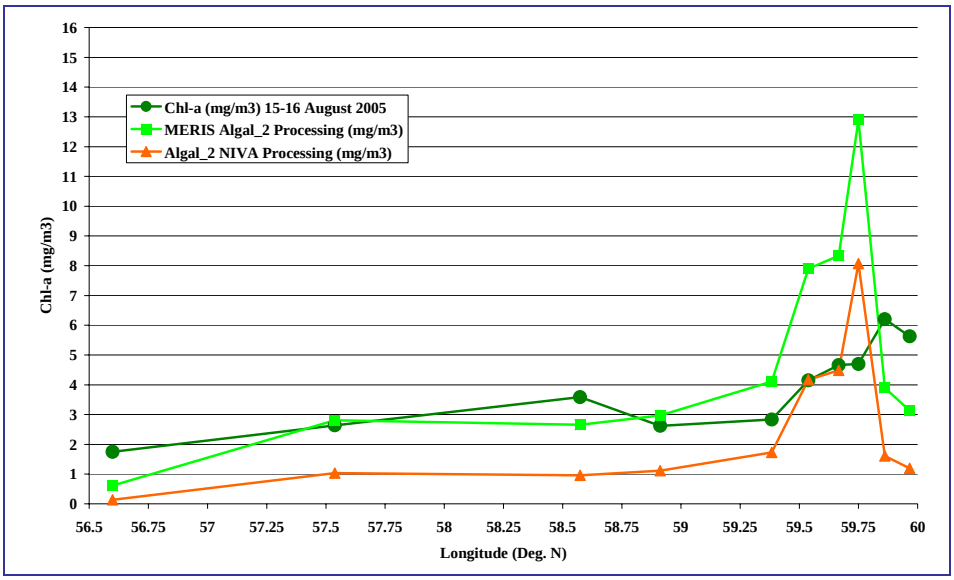

Figure 6-5: The transect between Travemünde and Helsinki on the 15 of August 2005 of the *in-situ* Chl-a from the FIMR route and MERIS algal product.

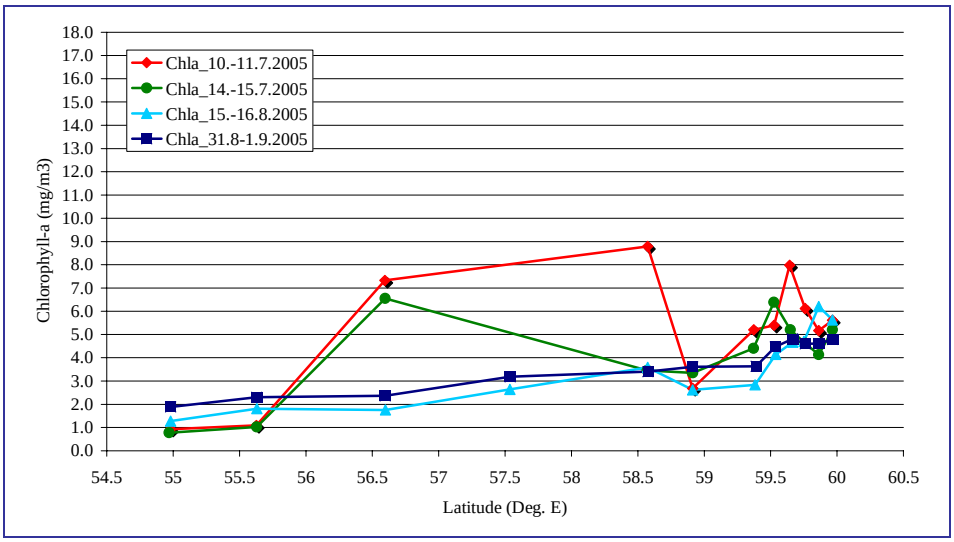

Figure 6-6: *In-situ* Chl-a before and after the Cyanobacteria bloom of *Nodularia Spumigena* in the Baltic Sea in summer 2005.

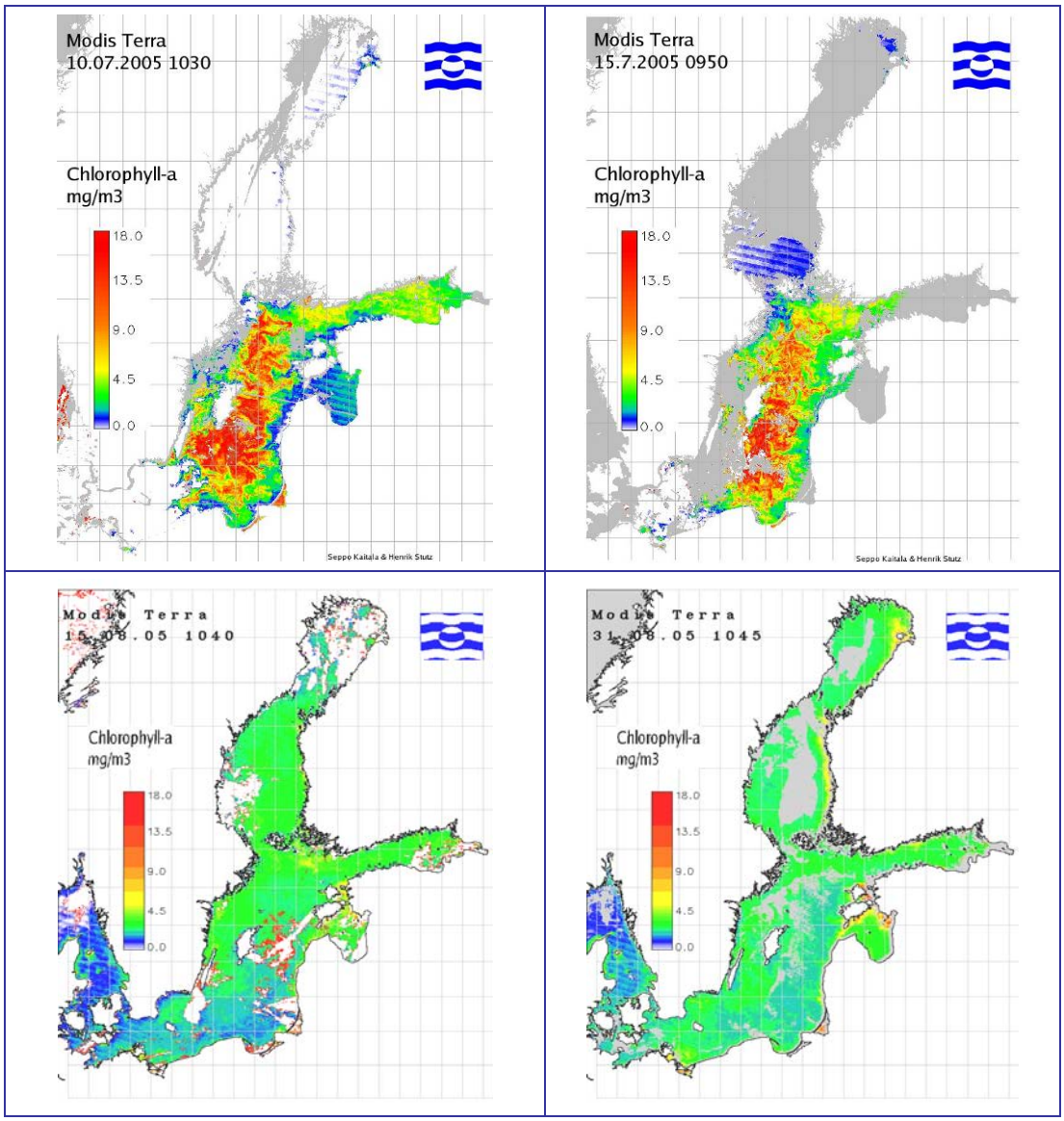

Figure 6-7: MODIS Terra algal product processed at FIMR illustrating the patchiness during a Cyanobacteria bloom of *Nodularia Spumigena* in the Baltic Sea during July 2005 and the lower Chl-a in August after the bloom.

6.2 Comparisons in the Skagerrak Sea

In the Skagerrak area the Ferrybox route covers daily (night and day time) the distance between Hirtshals and Oslo. Optically the water here is dominated by Case II, but with periods of Case I water in the central part. In this area validation activities for satellite data have been ongoing since 2002 (VAMP) and involves the present FerryBox activity. MERIS passes are available when the ferry is in the open Skagerrak area which makes it excellent for validation. In Figure 6-8 the area and the Ferrybox routes is shown.

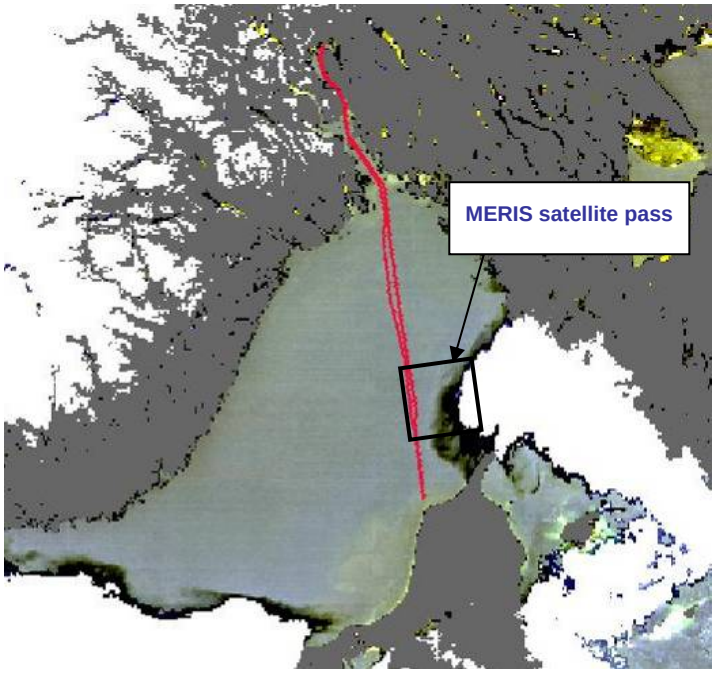

Figure 6-8: MERIS RGB image from 28 March 2003 with the Ferrybox routes of NIVA (night and day track shown). The area where the ferry is located during satellite pass of MERIS is indicated.

The first data examples are from the 28 March in 2003. Extraction of the two algal products from MERIS is shown in Figure 6-9, together with the Chl-a HPLC results determined from the water samples. Also the NIVA processing of Algal_2 product is shown indicating that this processing better fits the local optical properties of the area. Close to land however at the Danish side (57.6 °N) the deviation between the satellite products and the Chl-a is larger than in the central Skagerrak (58.1 °N). The main reason for this is probably the environmental effects of land, but also the error associated with the sampling in these dynamic water masses will influence the data.

In the Oslofjord area (from 58.9 °N) the MERIS products also fails and the MERIS data are flagged. In the central Skagerrak (58.1 °N) where the overpass of the satellite fits with the measurements from the ferry the satellite data are close to the *in-situ* data.

An algal_2 Chlorophyll-a product (image) was processed from this situation (Figure 6-10). This image is based on the Algal_2 product of the second reprocessing of MERIS ready in November 2005. This reprocessing is very close to the NIVA processing concerning the Chl-a concentration. North of 59° N and close to the Norwegian coast the effects of land influence the data.

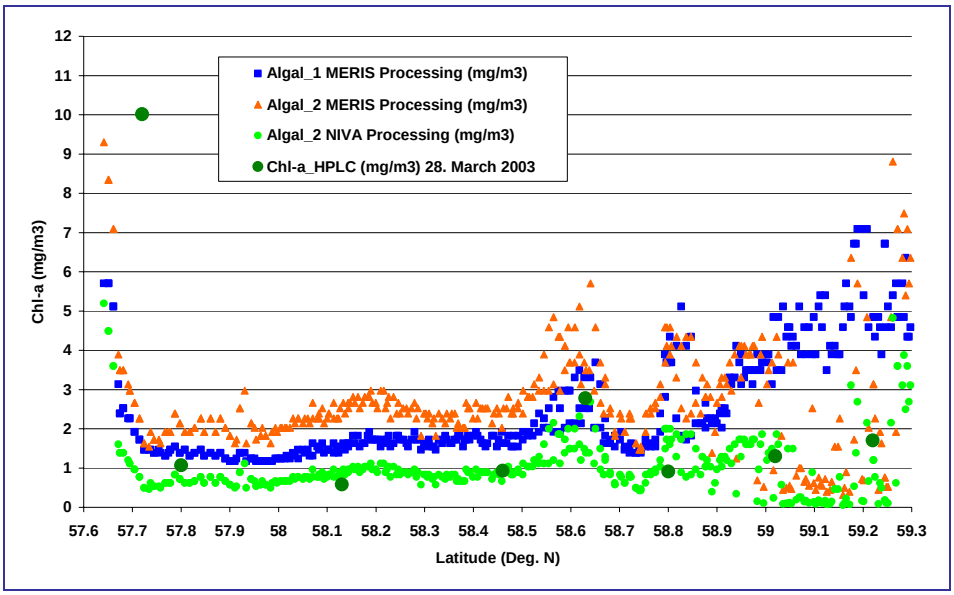

Figure 6-9: Transect of algal products from MERIS and the NIVA processing with *in-situ* Chl-a sampled with the Ferrybox system onboard "Color Festival' in the Skagerrak on 28 March 2003.

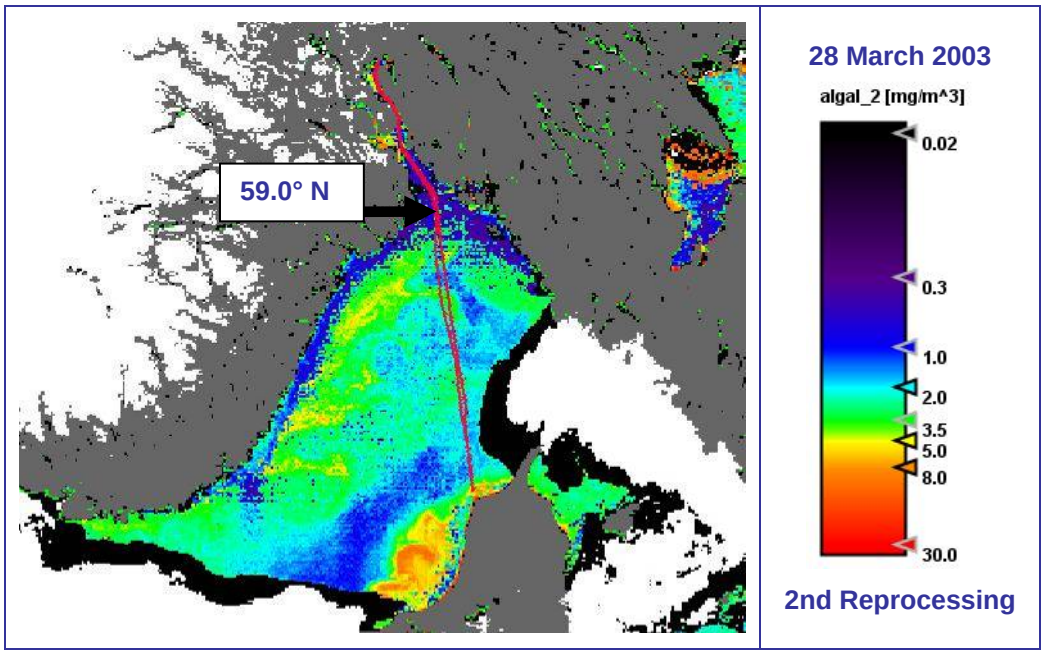

Figure 6-10: MERIS Algal_2 from the Skagerrak on 28 March 2003 based on the 2nd reprocessing of MERIS.

For this same situation a comparison between the Ferrybox turbidity and a calculated TSM based on a relation between turbidity and TSM (Section 4.2) and the MERIS TSM product is shown (Figure 6-11). There is a close relation in the open areas, but close to the coast the MERIS products fails due to environmental effects that in this MERIS processing is a problem. This example illustrates the usefulness of the turbidity sensor data from the Ferrybox to validate the TSM product.

An TSM (image) was processed from this situation (Figure 6-12) This image is based on the TSM product of the second reprocessing of MERIS ready in November 2005. The TSM product is not changed from the first to the second processing. North of 59° N and close to the Norwegian coast the effects of land influence the data.

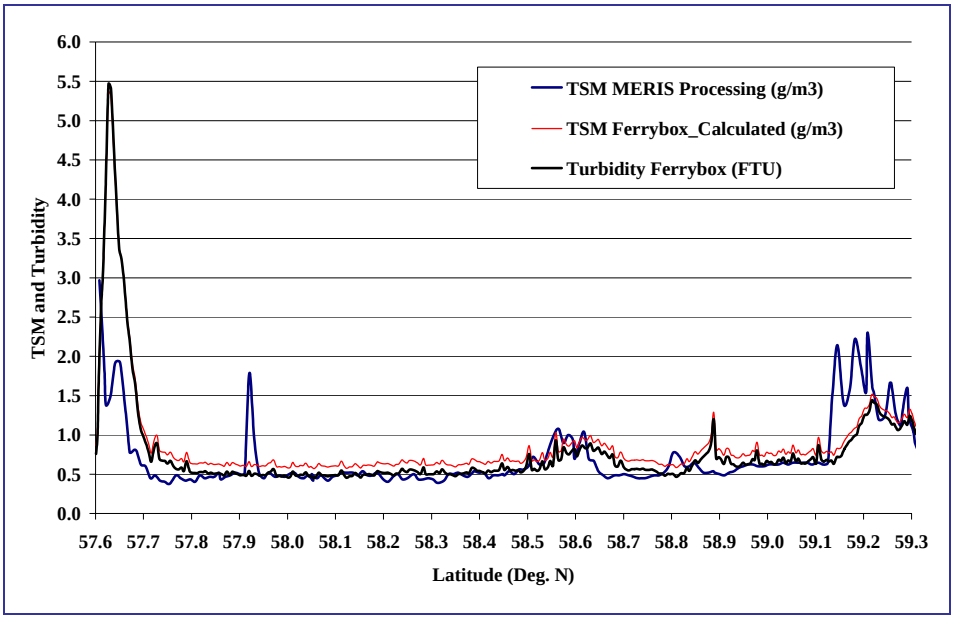

Figure 6-11: Transect of TSM product from MERIS and TSM calculated from the Ferrybox turbidity sensor from the Ferrybox system onboard "Color Festival" in the Skagerrak on 28 March 2003.

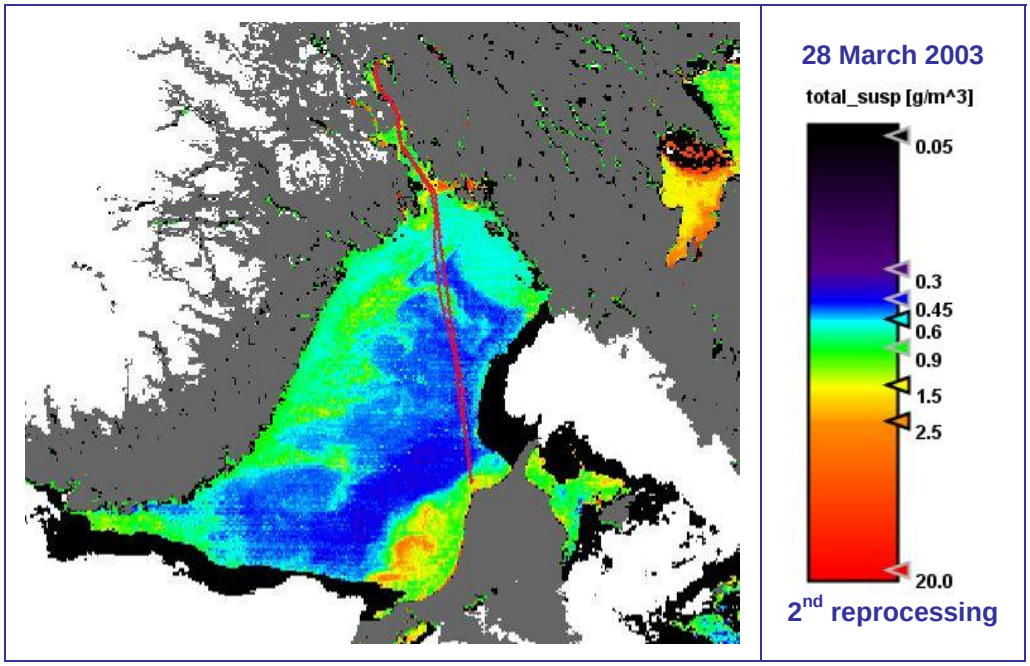

Figure 6-12: MERIS TSM from the Skagerrak on 28 March 2003 based on the 2nd reprocessing of MERIS.

Use of the Chl-a fluorescence data from the Ferrybox data when water samples are not available has been tested. An analysis of the day/night variation of the Chl-a fluorescence has been done as shown in Figure 6-13. The ferry route in the Skagerrak follows the line from Oslo to Hirtshals during night time leaving port around 18:00 UTC and arriving in Hirtshals about 06:00 UTC. The return journey daytime measurements are between 08:00 UTC and 16:00 UTC. This gives almost perfect day/night measurements. The time difference in measurements is then 2-3 hours at the Danish coast, about 10 hours in the Central Skagerrak and 20-22 hours in Oslo in the inner Oslofjord.

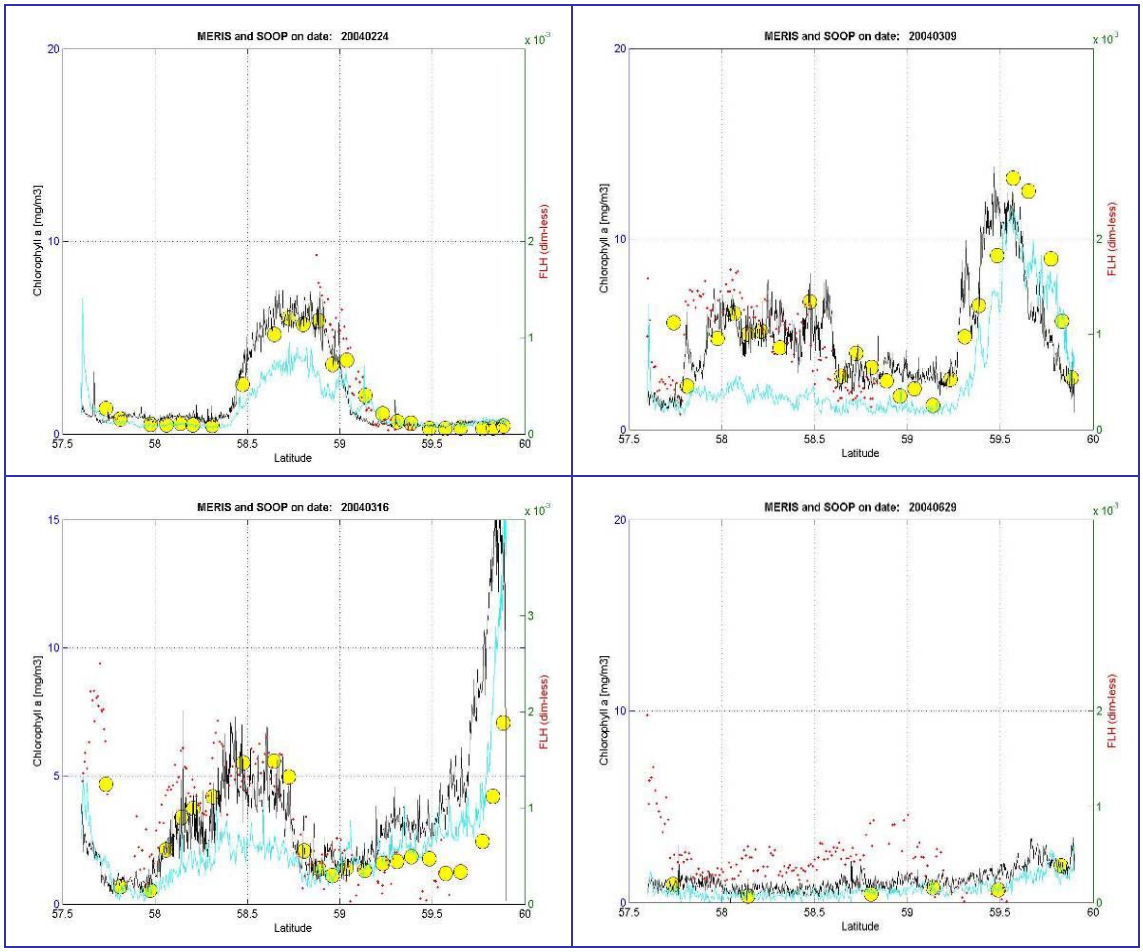

Figure 6-13: Comparison of the night (black) and day (blue) fluorescence, Chl-a (yellow) and the non-standard product FLH data (red) for some dates in 2004.(Upper left 24 February, upper right 9 March, lower left 16 March, lower right 29 June).

Figure 6-13 shows data from 4 situations in 2004 during the first spring bloom in February and March and one from a summer situation in June. The fluorescence is shown together with the water sampled Chl-a and the non-standard MERIS product FLH. From this it is clearly seen that the night fluorescence values are in better agreement with the Chl-a and that the difference between night and day can reach a factor 2-3. The overall correlation of the Chl-a and Chl-a fluorescence are good which make it possible to use also the Chl-a fluorescence data for validation, but one need to discriminate between night and day data to have the best comparison.

For the same datasets the MERIS 2 standard algal products as well as the FLH product were studied together with the Chl-a measured by HPLC (Figure 6-14). For the situation during the first bloom on 24 February the standard algal_2 product failed concerning the level of biomass while both algal_1 and FLH followed the concentration gradient, however the MERIS algal_2 has been observed to overestimate the Chl-a for the area. The second examples (9 March) follow the pattern except for algal_1 that fails. The two last datasets show situations where the MERIS data (i) fails probably due to the atmospheric correction (16 March) and (ii) one with low Chl-a concentration with fairly good agreement (29 June).

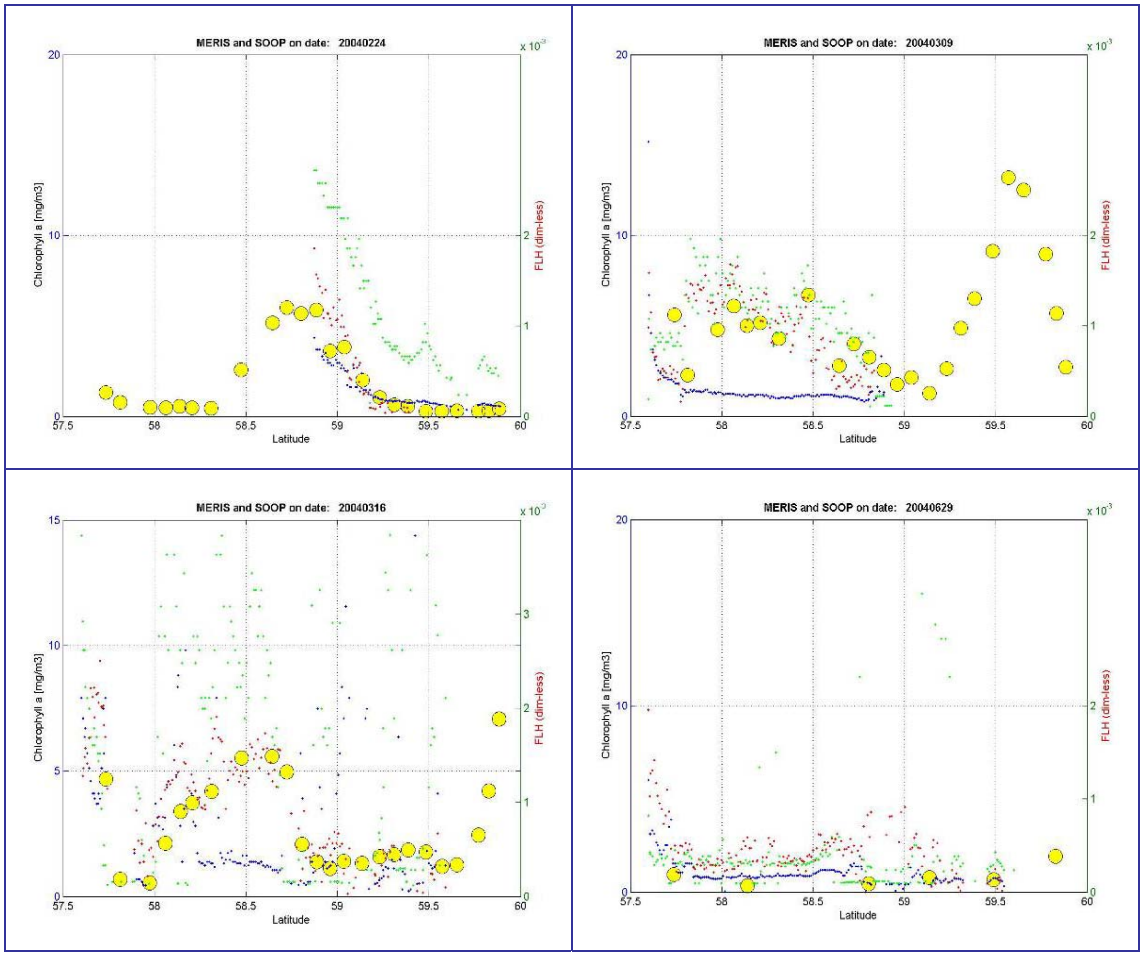

Figure 6-14: Comparisons of Chl-a from water samples collected from the Ferrybox system with MERIS algal products in 2004. (Upper left 24 February, upper right 9 March, lower left 16 March, lower right 29 June). (Yellow dots are: Chl-a_HPLC; blue, green and reds dots arerespectively: Algal_1, Algal_2 and FLH).

All these data examples clearly demonstrate that Ferrybox data contribute significantly to the understanding of the satellite data products both in terms of absolute values as well as the overall behaviour along a gradient of biomass and water masses along the coast (close to land) and in open areas.

In the Skagerrak and the North Sea the EU-project REVAMP has developed a Case II algorithm that was validated with the Ferrybox data from the 'Color Festival' line (Peters et al., 2005). Here we show some examples where the water samples collected by the Ferrybox systems are used (Figure 6-15). The situations in June 2003 show the failure of the algorithm during a Coccolithophore bloom of *Emiliania huxleyi*. In the pre-bloom situation at 6 June the

REVAMP Chl-a was in good agreement with the *in-situ* Chl-a, while during the bloom on 20 June the algorithm fails. The sampled and measured turbidity clearly show the higher scattering of coccoliths during the bloom. Here the turbidity samples (or the sensor data) are used together with the Chl-a data to interpret the situation.

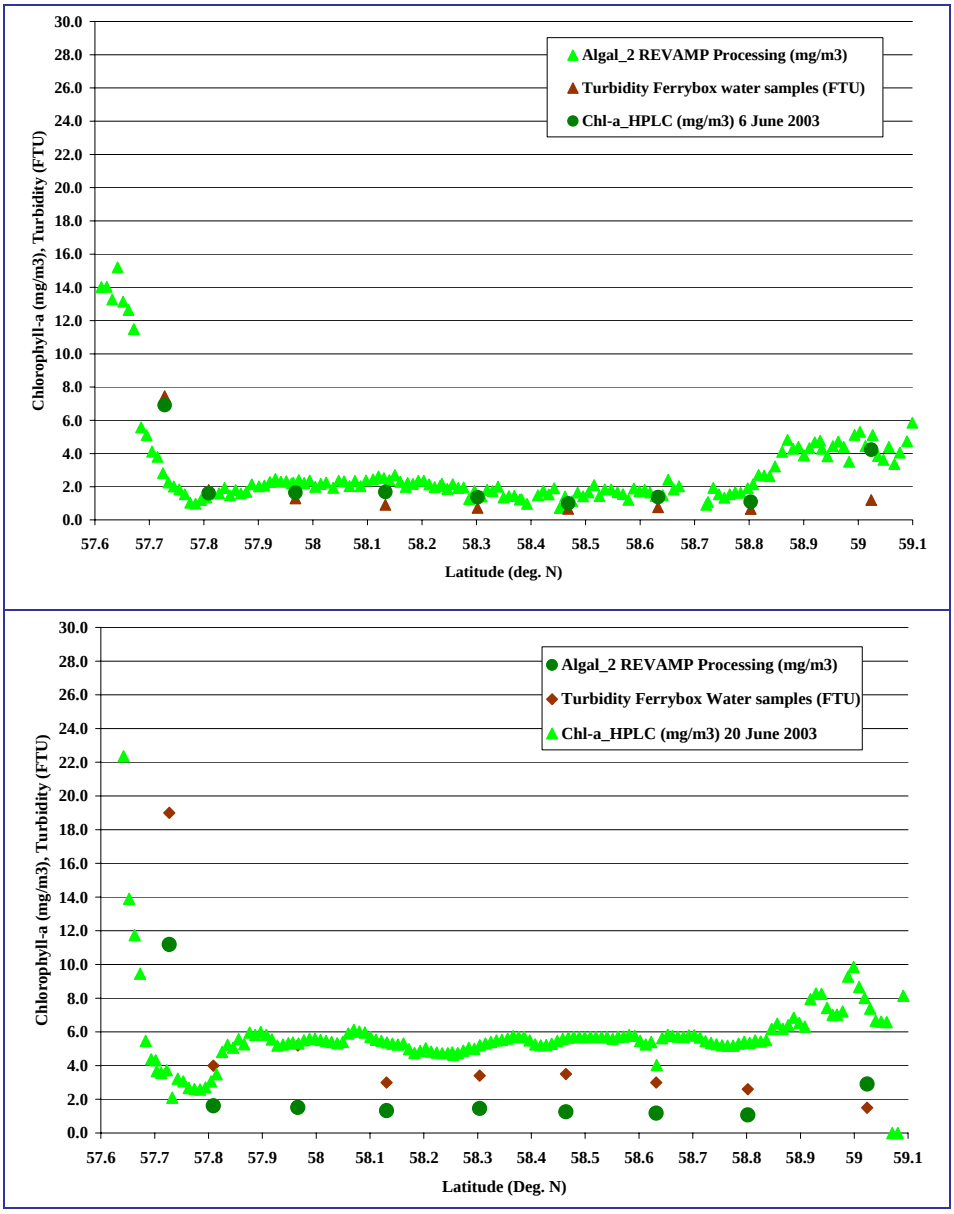

Figure 6-15: Validation of REVAMP algorithms in June 2003 before (top) and during (bottom) a *Coccolithophore* bloom in Skagerrak.

The examples used above have been based on daily passes of satellite or transect of data. These are often influenced by the local situation or atmospheric correction and cloud cover. Since both the Ferrybox data and satellite data work autonomously and an objective is to combine data from the two measuring platforms, it is of interest to see how this data can be used in long term monitoring.

We have used satellite data from the REVAMP data set from May in 2003 and averaged all the available satellite data and extracted the data along the Ferrybox route and calculated mean values and standard deviations. The same was done for the Ferrybox data and plotted together (Figure 6-16).

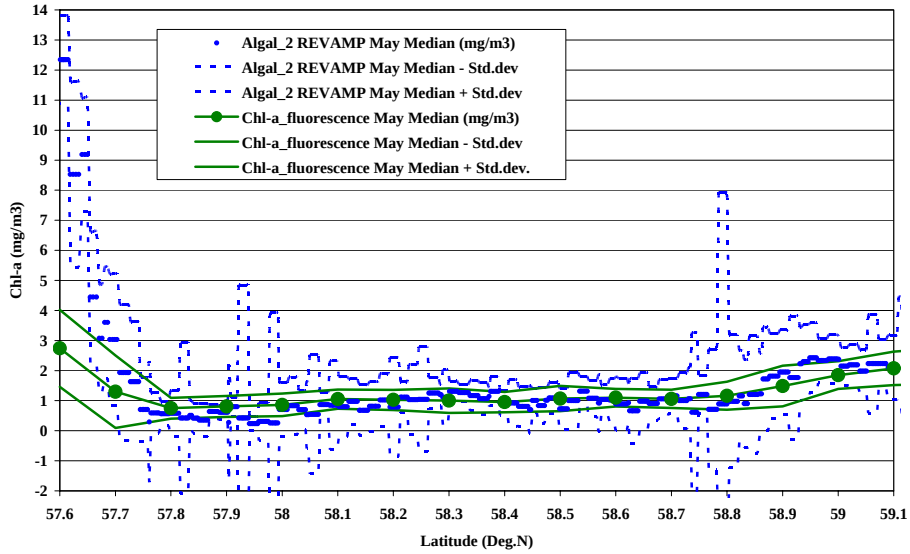

Figure 6-16: Median of REVAMP Chl-a and Chl-a fluorescence from Ferrybox data in May 2003.

This comparison of the satellite data by using Ferrybox data confirms the satellite data for this month and makes the satellite data more valuable. In Figure 6-17 an image of the REVAMP calculated Chl-a for May 2003 is shown (Peters et al. 2005).

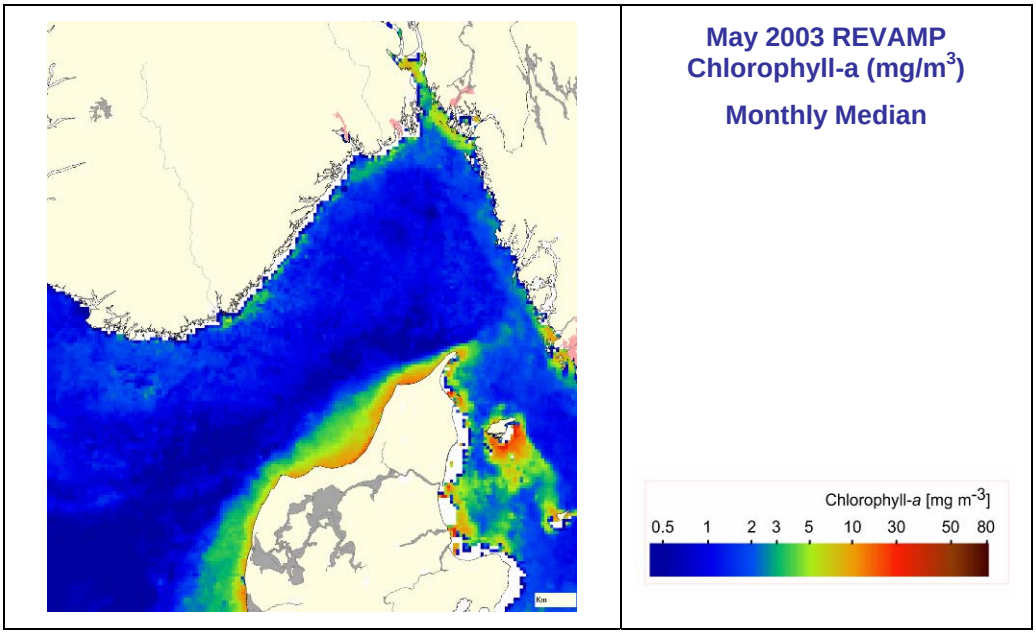

Figure 6-17: Monthly median of REVAMP Chlorophyll-a from May 2003 (Peters et al., 2005).

6.3 Comparisons in the North Sea

The North Sea area is covered by the ferry line between Cuxhaven and Harwich as operated by GKSS. The route takes 1.5 days starting around 15:00 UTC in the respective ports and arrives 09:00 UTC the next day. The ferry is therefore in harbour during satellite passes. The North Sea area has optically both Case I and Case II water covering very high sediment-laden water with variable algal blooms. Near Cuxhaven the ferry lines cross water masses that are influenced by the Elbe river, while at the English coast the turbidity is even higher due to erosion along the English coast. The EU-project REVAMP studied the satellite data for 2003 and illustrated the large patchiness of sediment and phytoplankton of the area, (Peters, et al., 2005). In Figure 6-16 a RGB image shows this patchiness as well as where the ferry lines crosses this area (as an example on 15 May 2005).

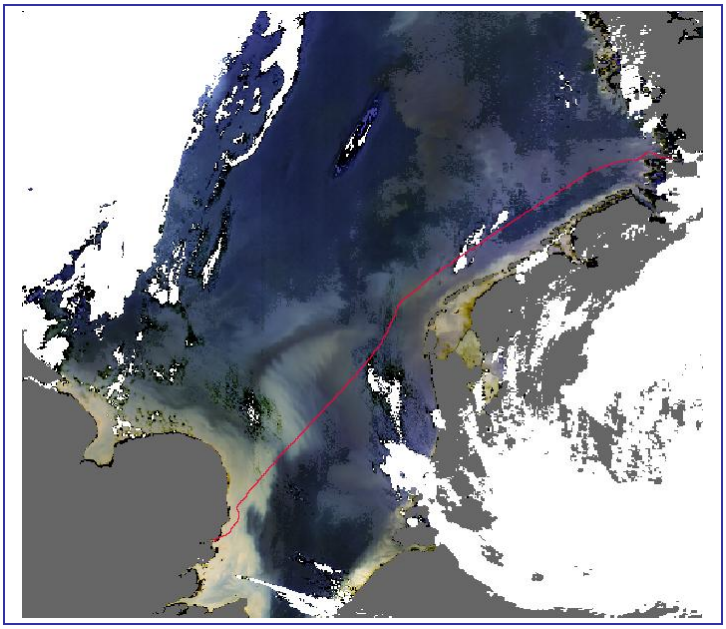

Figure 6-18: A MERIS RGB image from 15 May 2005 with the Ferrybox route of GKSS.

Figure 6-19 shows the transect data along the ferry line on May 15, 2005. The Chl-a fluorescence data from this sensor is based on the factory calibration and is given in relative values, and can not be used for comparing the absolute values. The comparison shows that the Ferrybox data resolves the main features of the different algal bloom peaks, but because no *in-situ* water samples are available the correct calibration of the sensor is not possible so no quantitative comparison of the products can be made.

The quality flags were also raised for this situation and some parts of the image are likely affected by sun-glint specially between 5° E and 7° E (Petersen et al. 2005). Overall the comparisons show good agreement between the main features in the image and the *in-situ* data. Both MERIS algal products are shown in Figure 6-19 and along the UK coast they resolve the same structures, but north of 5 °E they deviate, probably due to the sun-glint effect. Figure 6-20 show the Algal_2 MERIS image from this situation.

Due to the time difference between satellite passes and the Ferrybox measurements, modelling the movement of the water would have improved the comparisons. Such an approach has been demonstrated (Petersen, et al, 2005).

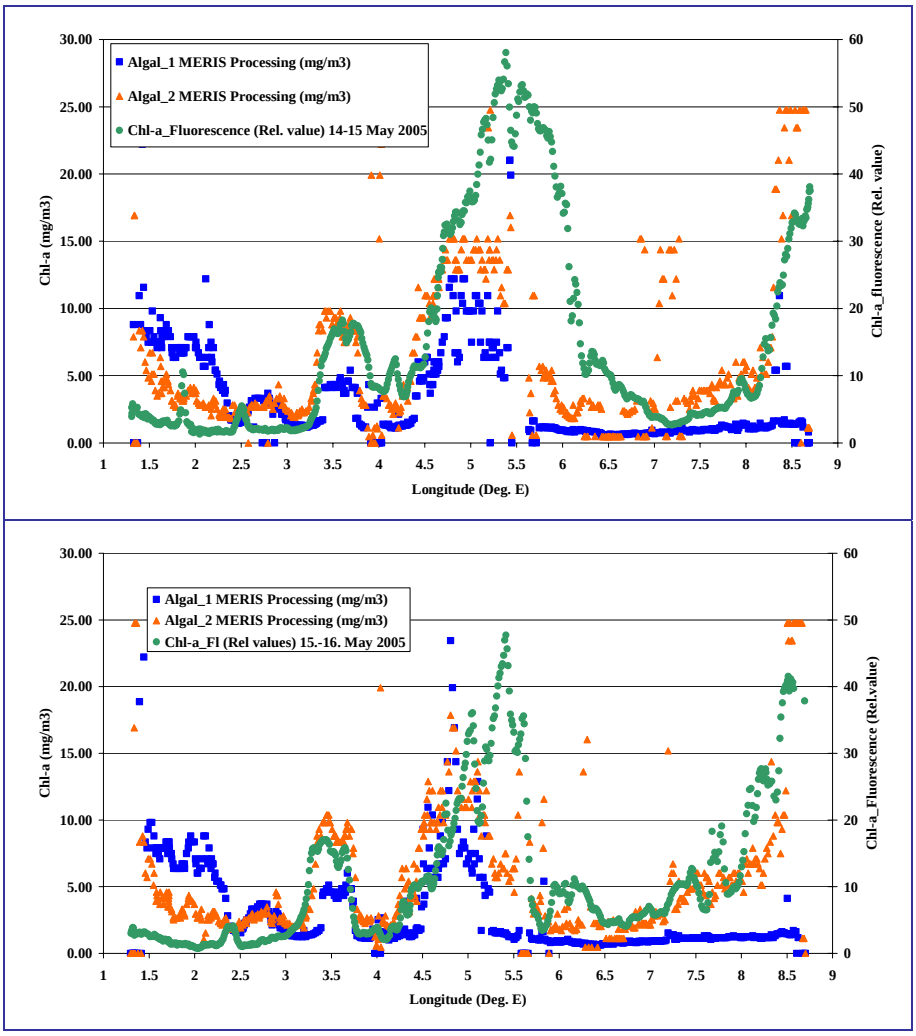

Figure 6-19: Transect of the Ferrybox data (14-16 May) and the MERIS algal products from 15 May 2005.

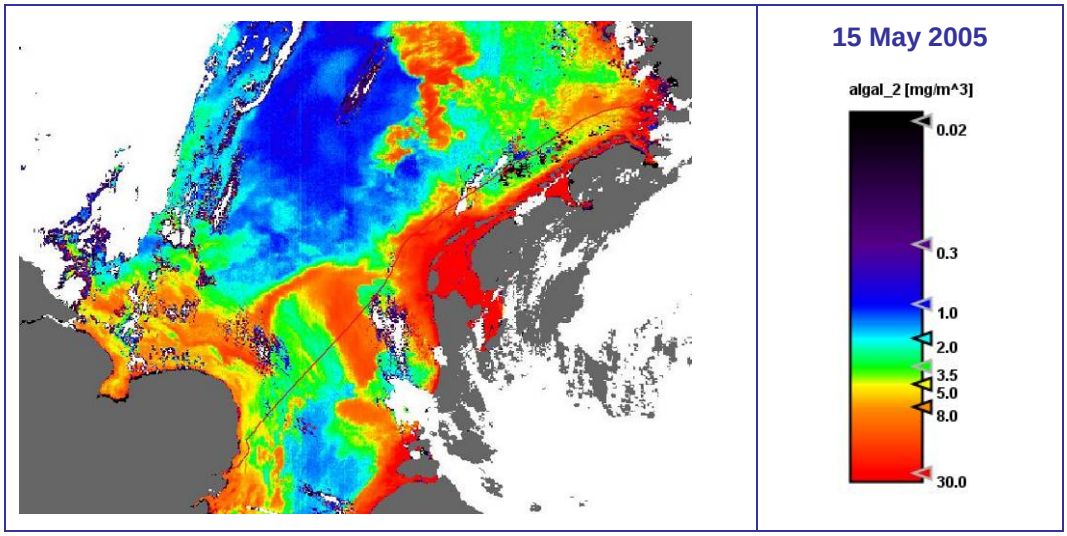

Figure 6-20: MERIS Algal_2 product from 15 May 2005 with the Cuxhaven – Harwich line operated by GKSS.

6.4 Comparisons in the Bay of Biscay

The Ferrybox operated by NERC.NOC covers the area from Portsmouth to Bilbao (PoB). This is supplemented by a Ferrybox operated by IEO on a small research vessel along the Spanish coast. The ferry was at sea at 47 °N during a satellite pass on the south track and 50 °N for the north track. The Case I waters dominate the route except for the coastal area of UK. The data from a situation on 11 May 2005 is analysed. Ferrybox data was available as well as Chl-a water samples from the NERC.NOC line and Chl-a fluorescence from IEO. The Ferrybox lines are indicated in Figure 6-21.

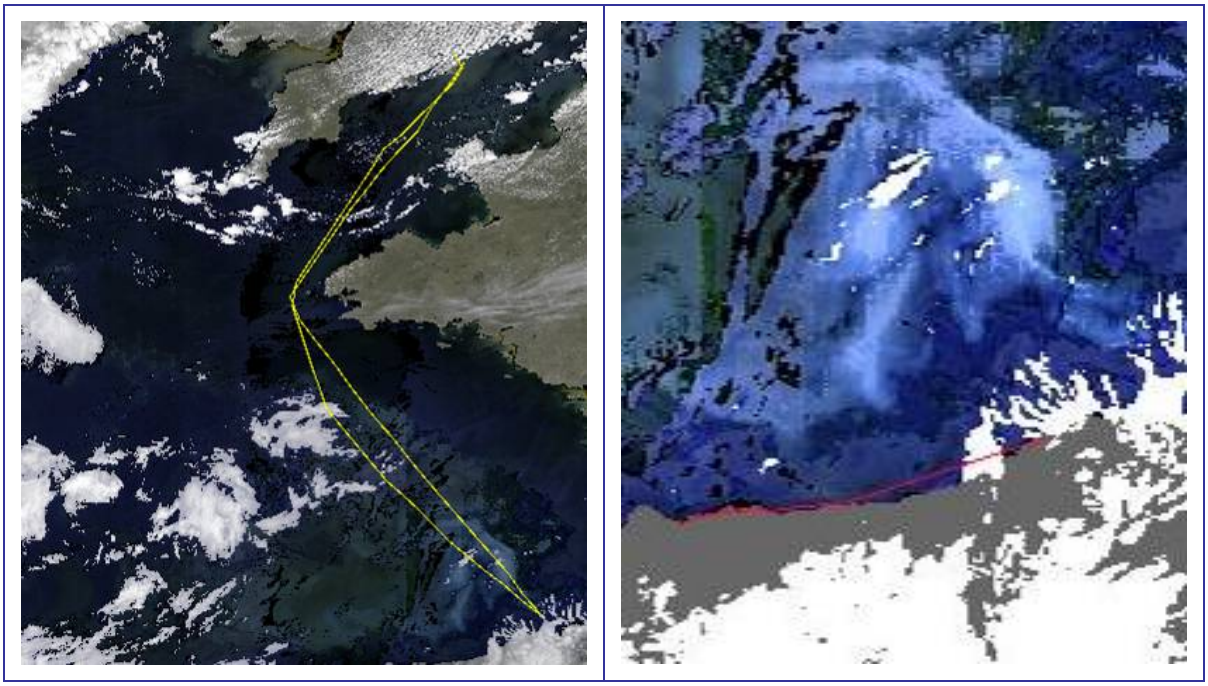

Figure 6-21: An MERIS RGB image from 11 May 2005 with the Ferrybox routes of NERC.NOC (left) and IEO (right).

In Figure 6-23 the data from the transect are shown using the MERIS algal_1 compared with the Chl-a from the water samples of NERC.NOC and the Ferrybox data from IEO. The Figure combines the dataset from the two lines.

The MERIS data from the IEO line are close to the coast and will be affected by the environmental effect from land. Also in the central Bay the atmospheric correction can be influenced by partial cloud cover (haze) which can explain the lower Algal_1 data compared to the *in-situ* data (45.5.47.5), while close to Bilbao at the Spanish coast (43.5 to 45.5 °N) there is good agreement. In the channel around 50 ^{o}N there are scattered data, but the average Chl-a concentrations are in the same range.

The route is interesting for validation since one have MERIS pass when the ferry is in Case II coastal waters of UK and one pass the ferry is in Case I waters.

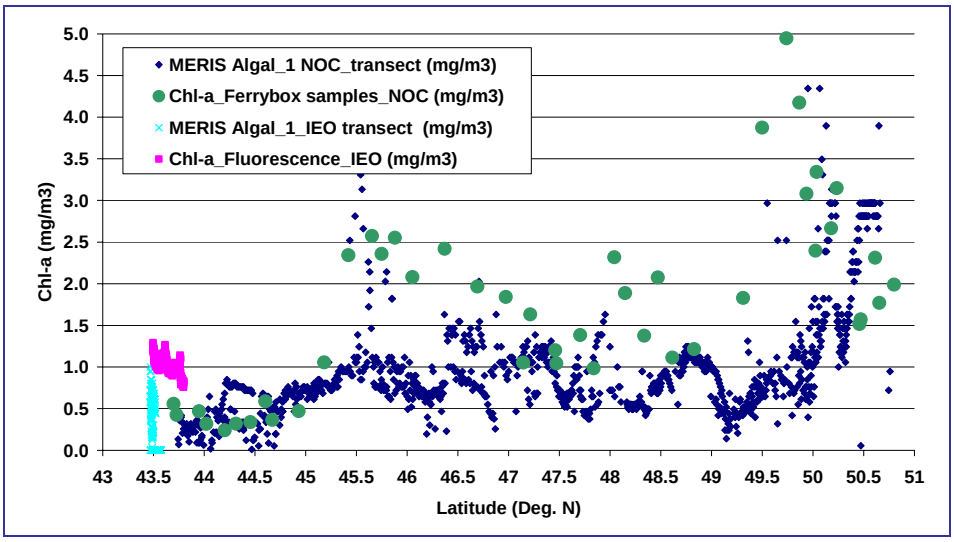

Figure 6-22: Transect data from 11 May 2005 from both FerryBox lines in the Bay of Biscay.

6.5 Comparisons in the Aegean Sea

In this area the HCMR FerryBox route performs a night travel between Athens and Heraklion. The area should have a typically Case I water characteristic with low suspended material and yellow substance. The ferry line with sampling stations from 16-17 June 2004 is shown in the RGB image from 16 June 2005 (Figure 6-23).

Figure 6-23: RGB image from the Aegean Sea on 16 June 2005 with HCMR's Ferrybox sampling stations along the Athens – Iraklion route.

In

Table 6-3 the *in-situ* Chl-a, and the MERIS algal products from the stations along the route are summarised. Included also for information is the MERIS yellow substance and the TSM products from the same track.

Table 6-3: *In-situ* Chl-a and the MERIS algal product from 16 June 2004.

Date	Time (UTC)	Latitude	Longitude	Chl-a Ferrybox (mg/m^3)	MERIS Algal_1 (mg/m^3)	MERIS Algal_2 (mg/m^3)	MERIS YS (m^{-1})	MERIS TSM (g/m^3)
16.06.2004	20:47	37.159	23.960	0.044	0.106	0.071	0.012	0.325
16.06.2004	22:17	36.656	24.194	0.058	0.098	0.064	0.011	0.302
16.06.2004	23:08	36.390	24.373	0.075	0.122	0.068	0.014	0.376
17.06.2004	00:25	35.995	24.671	0.046	0.122	0.073	0.014	0.362
17.06.2004	01:54	35.565	25.005	0.087	0.088	0.049	0.011	0.302
17.06.2004	02:28	35.404	25.136	0.036	0.059	0.044	0.009	0.163

Figure 6-24 shows comparison of MERIS algal products and Ferrybox measurements. The algal_1 products show values which are higher by a factor of 2, while the Algal_2 products are in better agreement with the *in-situ* data. On the station close to Heraklion algal_1 decreases almost to the level of the *in-situ* data.

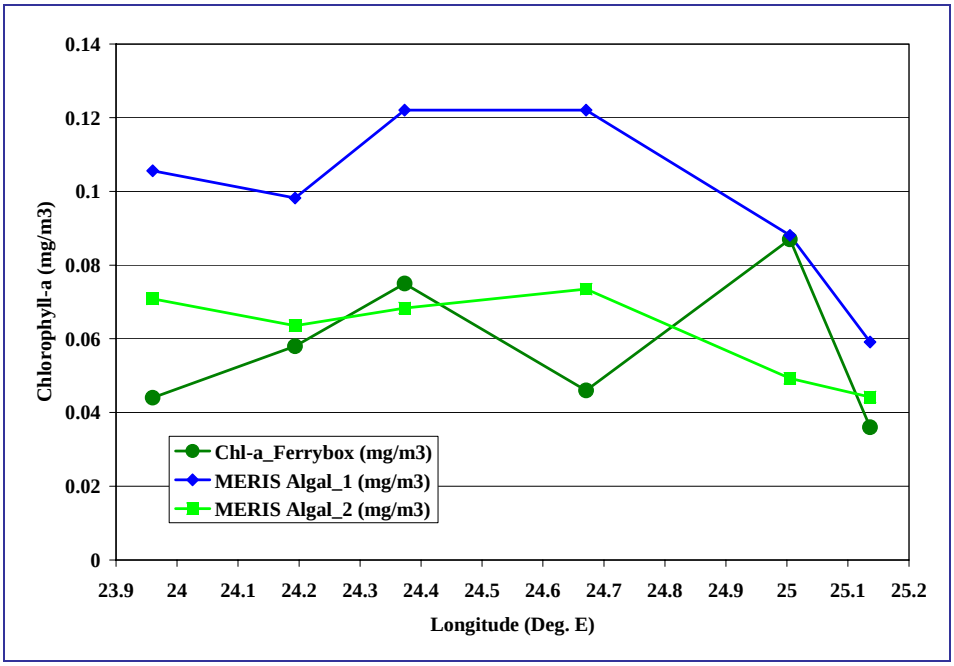

Figure 6-24: Comparing the *in-situ* Chl-a and the MERIS algal products for 16 June 2004.

To understand the failure of the MERIS products both the product quality flag and the marine reflectance should be analysed. As an example the reflectance of MERIS bands from the station is shown in Figure 6-25. The reflectance spectra look reasonable except for some negative reflectance values (overcorrection of the atmospheric correction from the processing).

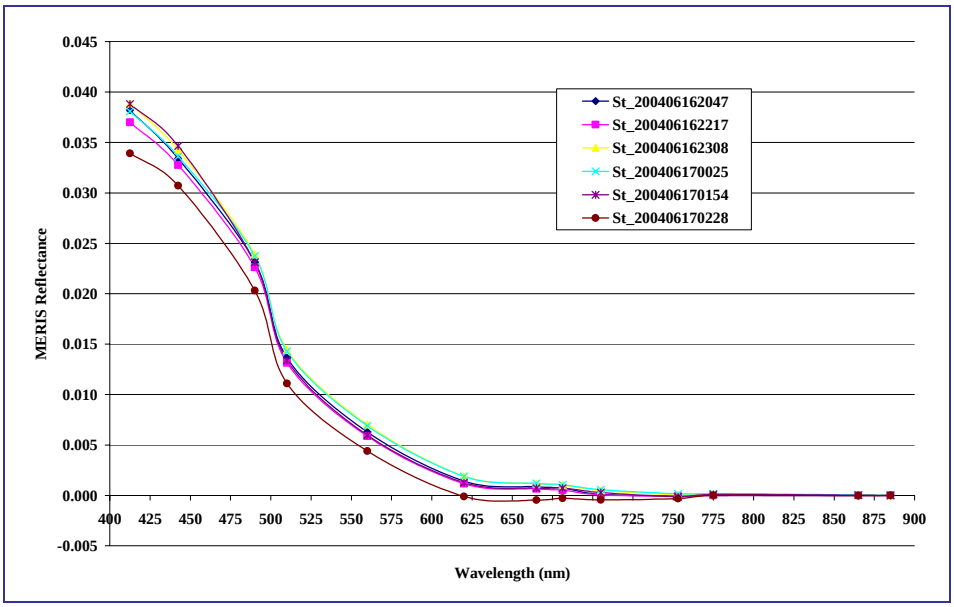

Figure 6-25: MERIS reflectance spectra for the 16 June 2004 image from the *in-situ* station positions.

The algal_1 product is used for the area as seen in Figure 6-26. When turning on the algal_1 product quality flags (colour black in the figure) there are some disturbances in the area of the stations as well as in the Eastern part of the image and in the outflow from the Black Sea. This can indicate a problem with the atmospheric correction that could also explain the deviation in the Chl-a values for the algal_1 product (Figure 6-24).

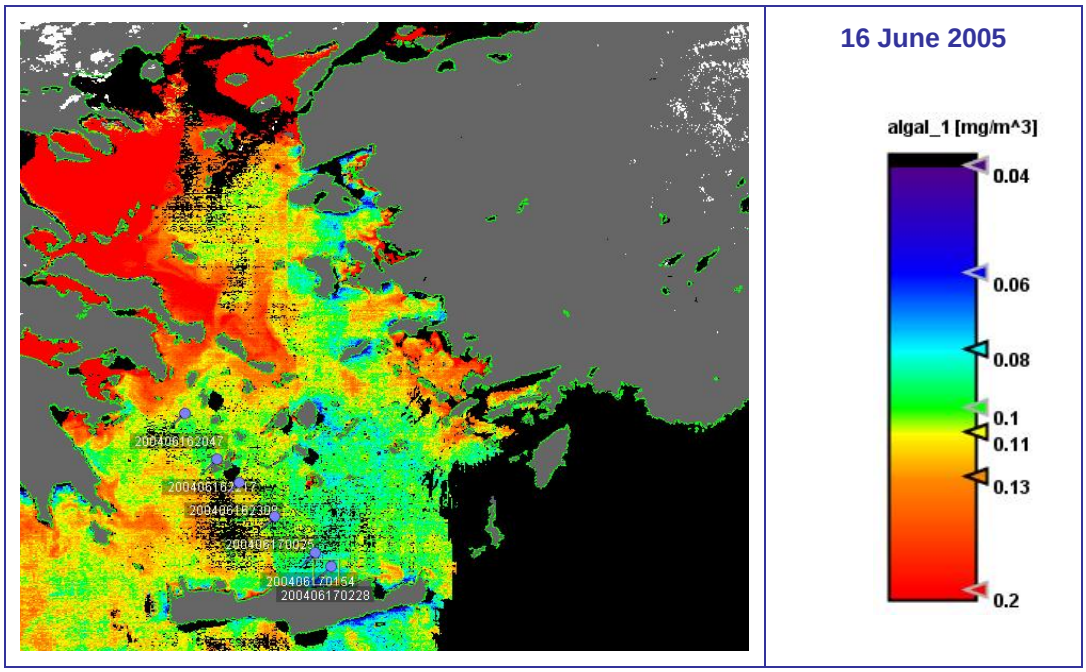

Figure 6-26: MERIS algal_1 with product quality flag turned on (black).

In Figure 6-27 the quality flag is turned off and the Chl-a concentration is also shown in the plume from the Black Sea. This is better seen in the RGB image indicating other water masses with different optical characteristics.

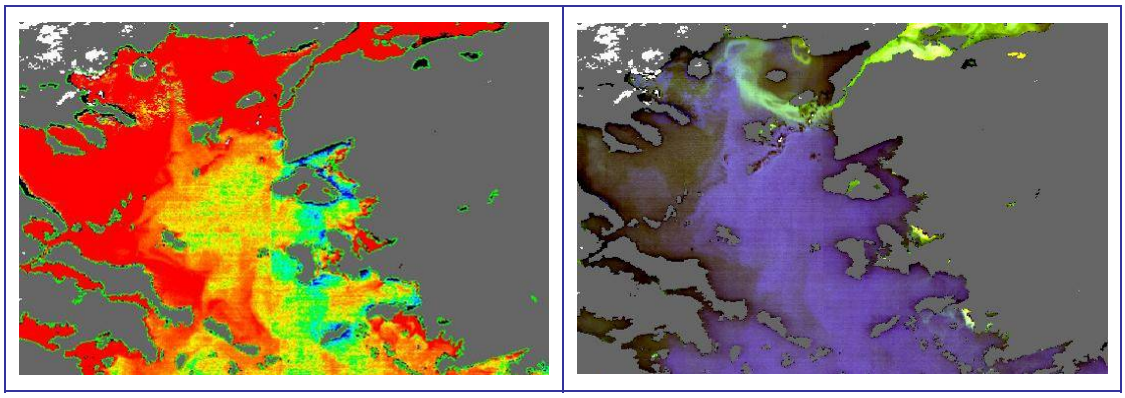

Figure 6-27: MERIS algal_1 with no product quality flag turned on (left) and the RGB image (right) from 16 June 2004.

7 Validation of AVHRR Sea Surface Temperature

The Irish Sea FerryBox has operated since Nov 2003 on its present route, Birkenhead to Belfast (Northern Ireland). Operating difficulties were intermittent in 2004, particularly relating to position recording, so we have chosen the period February to November 2005 (9/2/05 – 7/11/05) as the inter-comparison period. During this period the ferry made daily crossings, each crossing taking ~7 hours with planned start times of 1000 and 2200 each day. During July the ferry changed route, travelling from Birkenhead to Dublin (Eire) instead.

It is well known that satellite AVHRR images record skin temperature and that this is more variable during the day than at night. Thus for this work we have chosen to use the night-time crossings only for comparison with satellite images. All the available crossings between February and November 2005 are illustrated in Figure 7-1.

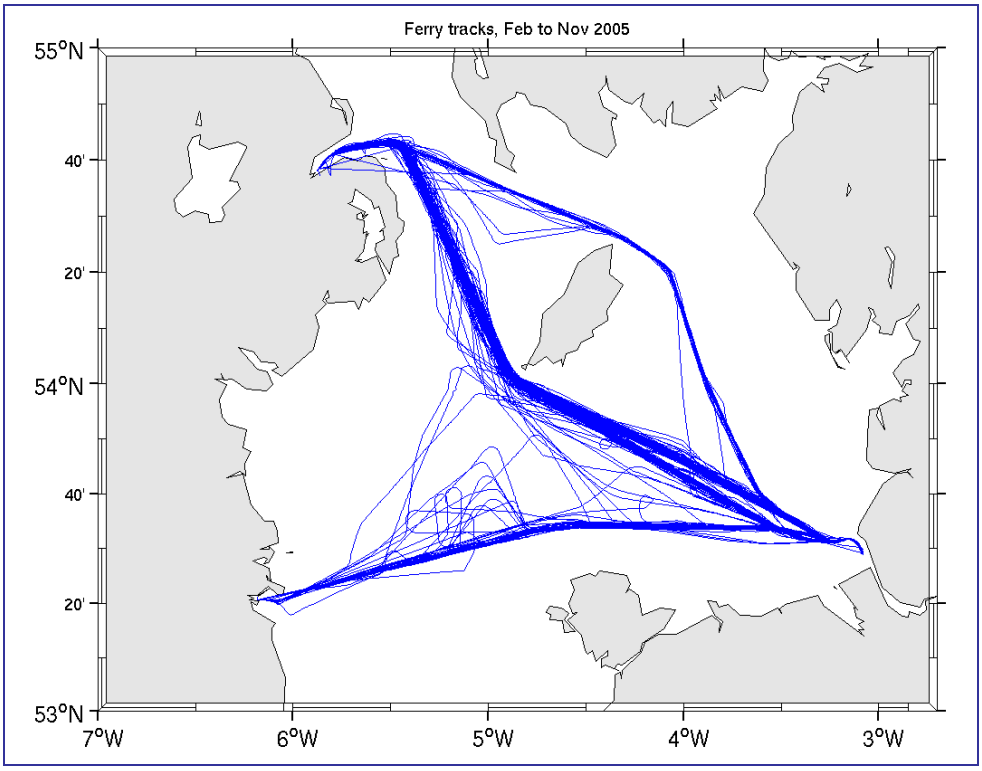

Figure 7-1: Ferry tracks transited in the Irish Sea from February to November 2005.

The French-processed SAF AVHRR SST data typically has 3-4 passes / day over the Irish Sea, with times approximating to 0200, 1000, 1200 and 2000. We have selected the 0200 passes each day where available. Here are 247 satellite passes in the period. Due to the high cloud density at these latitudes it is rare to get a totally cloud free image.

Figure 7-2 shows the image during the period with the maximum SST availability. Typical coverage is less than 30% and frequent near-total cloud cover means that no points in an image along the ferry track have SST values. Aggregating the Ferrybox data to 1 nautical mile bins provides 197600 data values. Interpolating the 2 km SAF data to 1 nautical mile and extracting values along the ferry tracks, and then extracting pairs of data where SAF SST data exists, results in 22344 matching pairs, which equates to 11.3% of the available Ferrybox SST data.

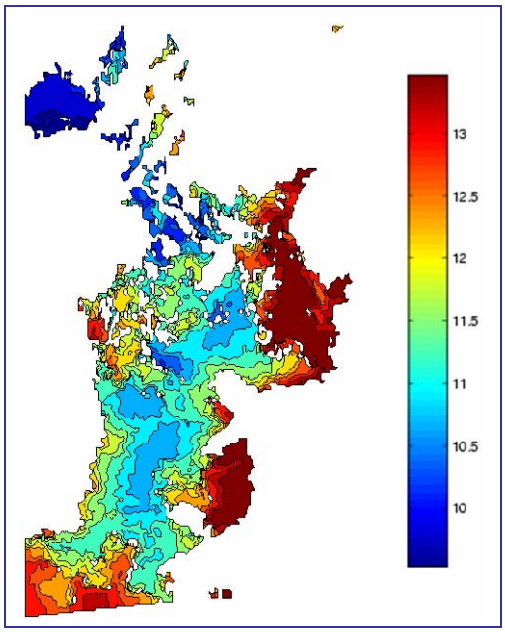

Figure 7-2: SAF AVHRR SST of 12 July 2005, maximum coverage in the period.

A direct comparison between FerryBox and SAF SSTs is shown in Figure 7-3.This shows day number in 2005 along the y-axis and data point (corresponding to the distance from Birkenhead to Belfast/Dublin) along the x-axis. The different numbers of points indicates the different routes taken and shows that even when passing between the same two ports the track length can vary significantly. The top panel shows the Ferrybox SST (in degrees C, dark blue here indicates zero values beyond the end of a track); the middle panel shows the SAF AVHRR SST where available along the ferry tracks; the bottom panel shows the difference in SST (FB-SAF) – no consistent difference is evident.

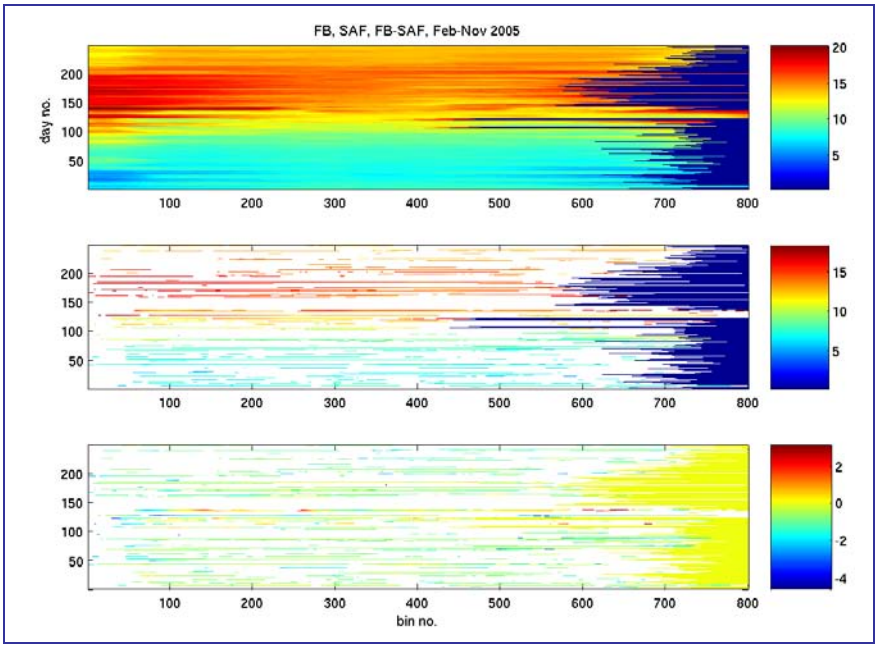

Figure 7-3: Available SST data from FerryBox (upper panel), SAF AVHRR (middle panel), differences between February and November 2005 (lower panel).

The 20,000+ matching pairs of data are plotted as a scatter plot in Figure 7-4. Here the x-axis is Ferrybox data, the y-axis the SAF data. Also plotted is a) the 1:1 line (black) and the linear regression line (red). There is a strong correlation between the datasets with a Correlation Coefficient of 0.9625. It can be seen that there is an offset between the two datasets. The regression equation for the two datasets is

$$SST_{SAF} = -0.587 + 0.9890 \times SST_{FB}$$

indicating that the SAF data is typically 0.5°C warmer than the Ferrybox data.

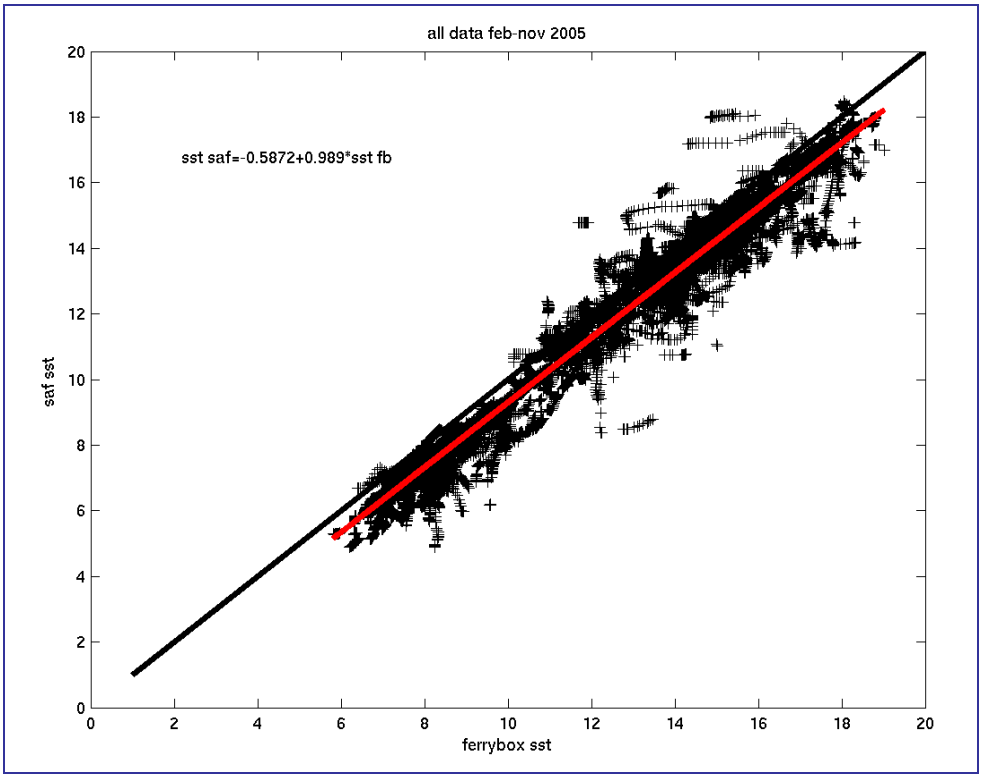

Figure 7-4: All SST data (x=FerryBox, y=SAF AVHRR), Februar to November 2005.

This may be a consequence of the different depths at which the two measurements are made. The good linear fit indicates that there is no seasonality (colder temperatures in winter, warmer in summer) in the relationship, and this can be evidenced in Figure 7-4.

8 Conclusions and Summary

Ferrybox parameters like Chl-a fluorescence and turbidity can, with proper calibration, be used for validation purposes of satellite data. Using Chl-a fluorescence is complicated by the diurnal variation of Chl-a fluorescence and the non-constant relation to Chl-a determined *in vitro*, but if this is considered using seasonal calibration and night fluorescence (if possible) the data will be valuable in the validation. Sensor measurements along a transect give more information than point measurements and give insight in the (for example) close-to-land problems that the optical satellite data have.

The possibility to sample remote areas under clear sky conditions either by fixed positions or remotely triggered will be very valuable to increase the number of satellite validation points in a cost-effective way. From sampled water all the geophysical satellite products can be validated e.g. Chl-a, suspended material and yellow substance. This can be done on ferries that come to port less than a day after sampling so the water can be processed for analysis.

A study of the possible use of Ferrybox data for validation of satellite data has been performed for five regions where ferries from the EU-project FerryBox operate. The most complicated area was the Baltic Sea with the high biomass of the Cyanobacterium *Nodularia Spumigena* and typically Case II waters. The complicated vertical and horizontal patchiness make it in theory (validation protocols) impossible to do correct validation in this area. Nevertheless, this is an important area for studying eutrophication and new methods and remote sensing products need to be developed and validated from this area. Such phenomena are interesting for studying exceptional spectra to support the training of neural network systems. During periods where such extreme blooms occur the area has the normal Case II water problems concerning validation, but with high yellow substance concentration.

Areas like the Skagerrak show that Ferrybox data are very valuable for validation. Here the validation activity has been planned from the start with focus on water samples and analysis of the geophysical products. Also the Chl-a fluorescence is used here due to the clear night and day time transect that can separate the diurnal effect more clearly than for the other routes that operate over longer distances with more variable light conditions and phytoplankton species. Also the use of monthly median values of data from the two platforms is very useful to show that the data can be used in longer term monitoring. The combination of Chl-a fluorescence or Chl-a with turbidity data are valuable to interpret phenomena such as coccolithophorid blooms.

For the complex North Sea area and the long ferry line crossing the Channel and into the Bay of Biscay the mixture of Case I and II waters gives the opportunity for comparison between satellite data and Ferrybox from a high phytoplankton situation to a high sediment concentration. The long routes and the very different water types that are found within the operation area of the ferries make the data difficult to interpret. The use of models to aid the explanation of water movement shows promising results (which are reported in Deliverable D-5-1). The validation using water samples will be easier in this area, but the Chl-a fluorescence transect clearly follows most of the surface patchiness seen by the satellite. However, if there is a high subsurface bloom the Ferrybox data cannot be expected to provide information of these structures.

In the pure Case I water types in the Aegean Sea the Ferrybox route should give excellent possibilities to validate satellite products. Here the use of water samples would be preferable until proper calibration data for the sensor data is established.

A general challenge to validate satellite data using *in-situ* data from different validation teams (FerryBox partners) is that the analytical methods vary and the variability between laboratory results of Chlorophyll-a can be high. The Chl-a inter-comparison showed that most of the results were within +/- 1 standard deviation, and most of these variations seem to be due to the very different methods involved. One laboratory (NIVA) also performed tests on the different methods showing the difference between HPLC and the spectrophotometric techniques. This variation must be taken into consideration when we use *in-situ* data for satellite validation and this effect comes in addition to the deviation for common validation protocols when we use data collected from Ferrybox systems.

In addition to validation which the Ferrybox data have shown it benefit the data can be used in algorithms development and improvements. The Ferrybox data from Skagerrak has been used by success by developing analytical Case 2 algorithms (Folkestad, 2006).

Ferrybox measured turbidity based on sensor data measuring the scattered light in the red part of the spectrum following the ISO turbidity standard can be used for validation. When the sensor data are properly converted to a turbidity value one can establish a turbidity/TSM ratio for converting Ferrybox turbidity data to TSM, and compare with the satellite TSM products. Also here sampling of water and direct analysis of TSM will be the optimum strategy.

Comparing SST with the FerryBox-determined temperature has not been extensively investigated in the project since proper equipment like an *in-situ* radiometer measuring the true skin temperature has not been used or been available. In general the skin temperature as measured by a remote sensor can sometimes be significantly higher in the few upper millimetres during warm and calm days.

Comparison with a bulk temperature measured *in-situ* with a FerryBox sensor is not directly comparable during such situation. In the Irish Sea the data from the Ferry between Birkenhead and Belfast (and for a short period to Dublin) have been used to compare the Ferrybox temperature with AVHRR skin temperature. The AVHRR data are the French-processed SAF data and the data from the night pass was used to minimise the skin temperature effect. Data from the period February to November 2005 was used.

The results show that the SAF data was typically 0.5 ^{o}C warmer than the Ferrybox data. This may be a consequence of the different depths at which the two measurements are made. The good linear fit indicates that there is no seasonality (colder temperatures in winter, warmer in summer) in the relationship.

A brief investigation into the increased temperature of the Ferrybox data was made to assess if it was due to heating in the ship pipework. Direct comparison of the Ferrybox data with a fixed buoy in Liverpool Bay with a sensor 1 m below the surface, showed a mean difference of 0.11 °C. This indicates the SST measured by the ferry is close to that at 1 m depth, suggesting little heating in the tubing, probably because of the fairly high flow rate of the Ferrybox system.

9 New and Non-standard Sensor for Validation

A sensor that can be of great importance for validation of satellite data is the above water radiance sensor that measures the water leaving radiance and where the water reflectance can be calculated. This will measure the ocean colour signal directly and the marine reflectance of the satellite can be validated in real time if the data are transferred. The challenge is to deploy the sensor such that the effect of sun-glint and ship shadow is eliminated. If the ship is at sea during the satellite pass very good data can be collected. Sensors that can be used for such measurements are the TriOS RAMSES radiance sensors. As a part of the EU-project DISMAR NIVA has tested such a system with good results and this has already been implemented on two ferries in Norwegian waters. Such data are used in the ESA VAMP project for MERIS validation in the Skagerrak. The NIVA ferries with real time data can be seen at www.ferrybox.no.

The data from the TriOS Ramses sensor can also be used for validating Photosynthetic Available Radiation which is also a MERIS product. PAR is important in the interpretation of the FLH signal discussed in Section 6.2.For measuring PAR only other standard light sensors can be used (e.g. LiCOR), but it is recommended that sensors based on RS 232 communication of the weak light signal be used.

Another optical quantity that is of importance for satellite products is yellow substance. The MERIS yellow substance (YSBPA) is defined differently to traditional yellow substance (YS, CDOM), so this MERIS product is impossible to validate directly. However, CDOM could theoretically be measured optically if one could use in-line filtration and spectrophotometric measurements. Some systems for CDOM has been tested (TriOS VIS and UV optical Analyser), but the measuring principle is different from a validation protocol which needs the absorption at 442.5 nm. (See FerryBox report D-2-4 report on non-standard sensor for the optical analyser).

This study investigated briefly the Sea Surface Temperature using the bulk temperature from the Ferrybox system in the Irish Sea. A sensor that measures the true SST is planned to be implemented on the ferry in Skagerrak by the Space Science and Technology Department at the Rutherford Appleton Laboratory. This is a self-calibrating filter radiometer capable of measuring the brightness temperatures to 20 mK and skin SSTs to 0.3 K. This SISTeR (Scanning Infrared Sea surface Temperature Radiometer) is a compact in-situ radiometer, designed to validate A(A)TSR SSTs (Tim Nightingale, pers. comm.).

Experiments are now ongoing for testing a future Sea surface salinity sensor from space (SMOS). In 2006 field campaigns will be performed (CoSMOS-OS, Joe Tenerelli pers. comm.) and the use of Ferrybox data could be highly valuable for such a study. The subsurface measurements of a Ferrybox system is not optimum for validating a sensor measuring the surface, but if the upper layer is homogeneous vertically it can be used. Nevertheless the gradient information from a ferry line during a flight campaign will be valuable (the value of Ferrybox measurements for identifying salinity gradients has been reported in D-5-1).

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