FerryBox:

From On-line Oceanographic Observations to Environmental Information

EU Project FerryBox 2002−2005

www.ferrybox.org

Edited by W. Petersen[1], F. Colijn[1], D. Hydes[2] and F. Schroeder[1]

---

1. GKSS Research Centre, Geesthacht, Germany
2. NOC, Southampton, United Kingdom

EuroGOOS Personnel

Secretariat	Hans Dahlin (Director)	EuroGOOS Office, SMHI, Sweden
	Patrick Gorringe (Project Manager)	EuroGOOS Office, SMHI, Sweden
	Siân Petersson (Office Manager)	EuroGOOS Office, SMHI, Sweden
Chair	Peter Ryder	
Board	Sylvie Pouliquen	Ifremer, France
	Enrique Alvarez Fanjul	Puertos del Estado, Spain
	Kostas Nittis	HCMR, Greece
	Bertil Håkansson	SMHI, Sweden
	Jan H Stel	NWO, Netherlands
	Martin Holt	Met Office, UK
	Glenn Nolan	Marine Institute, Ireland
	Klaus-Peter Kolterman	IOC UNESCO
Task Team Chairs	Stein Sandven	Arctic Task Team
	Erik Buch	Baltic Task Team/BOOS
	Sylvie Pouliquen/Alicia Lavín	Iberia Biscay Ireland Task Team/IBI-ROOS
	Nadia Pinardi	Mediterranean Task Team/MOON
	Martin Holt	North West Shelf Task Team/NOOS

EuroGOOS Publications

1.	Strategy for EuroGOOS 1996	ISBN 0-904175-22-7
2.	EuroGOOS Annual Report 1996	ISBN 0-904175-25-1
3.	The EuroGOOS Plan 1997	ISBN 0-904175-26-X
4.	The EuroGOOS Marine Technology Survey	ISBN 0-904175-29-4
5.	The EuroGOOS Brochure 1997	
6.	The Science Base of EuroGOOS	ISBN 0-904175-30-8
7.	Proceedings of the Hague Conference, 1997, Elsevier	ISBN 0-444-82892-3
8.	The EuroGOOS Extended Plan	ISBN 0-904175-32-4
9.	The EuroGOOS Atlantic Workshop Report	ISBN 0-904175-33-2
10.	EuroGOOS Annual Report 1997	ISBN 0-904175-34-0
11.	Mediterranean Forecasting System Report	ISBN 0-904175-35-9
12.	Requirements Survey Analysis	ISBN 0-904175-36-7
13.	The EuroGOOS Technology Plan Working Group	ISBN 0-904175-37-5
14.	The BOOS Plan 1999-2003	ISBN 0-904175-41-3
15.	Bio-ecological Observations in OO	ISBN 0-904175-43-X
16.	Operational Ocean Observations from Space	ISBN 0-904175-44-8
17.	Proceedings of the Rome Conference 1999, Elsevier	ISBN 0-444-50391-9
18.	NOOS—Strategic Plan	ISBN 0-904175-46-4
19.	Proceedings of the Athens Conference 2002, Elsevier	ISBN 0-444-51550-X
20.	The EuroGOOS Brochure 2004	
21.	The Policy Basis of the “Ecosystem Approach” to Fisheries Management	ISBN 91-974828-1-1
22.	The Arctic Ocean and the Need for an Arctic GOOS	ISBN 91-974828-0-3
23.	Proceedings of the Brest Conference, 2005, European Commission	ISBN 92-894-9788-2
24.	IBI-ROOS Plan: Iberia Biscay Ireland Regional Operational Oceanographic System 2006–2010	ISBN 91-974828-3-8
25.	FerryBox: From On-line Oceanographic Observations to Environmental Information	ISBN 978-91-974828-4-4

Contents

Preface

In the EuroGOOS Strategy from 1996 the members agreed on an overall strategy to progressively deploy new instruments, data transmission systems and establish modelling centres. For the observing systems the targets were to:

- collaborate in using the most cost-effective and advanced technology which supports the gathering of operational data

and to:

- establish designs for the optimum observing scheme
- improve the procedures for optimising the observing system
- manage the review and trials procedures to assist in phasing in of new technology.

Ships-of-opportunity had for several years been used to reduce costs in relation to traditional methods of *in situ* observations. Cost advantages had been shown, and ships also enabled installation of advanced technology. The first meeting of the EuroGOOS Ferry Box Working Group in Southampton in April 1996 concluded that it was technically feasible to install mass-produced standard instrument packages on commercial ferries, and that the ferry operators were in principle interested in the project.

The Working Group made twelve recommendations, which were eventually included in project proposals to the European Commission.

EuroGOOS has been pleased to follow the development and the accomplishment of the FerryBox Project, and is now happy to publish a report on the main achievements of the project. The next goal is to transfer the ferry box lines established by the project into a sustained part of a European ocean observing system, and then to continue to establish new lines to fill gaps in the observations.

With many thanks to the authors I hope that this publication will serve as a guideline for the continued establishment of ships-of-opportunity observations.

Hans Dahlin
EuroGOOS Director

1 Executive Summary

1.1 Rationale

The EU Science Framework 5 funded the highly successful project “FerryBox” from 2002 to 2005. The project enabled the cooperation of 11 organisations and established the coordinated use of commercial ferry ships for the collection of scientific data. This has been an important step towards achieving the cost-effective extension of the European marine observational and reporting network envisioned in the EuroGOOS concept.

The 11 partners operated on 9 shipping routes around Europe, from the eastern Mediterranean to the Baltic. Four core parameters were measured on all the routes, alongside other route-specific measurements. Common data quality control and archiving procedures were adopted, and the data from the project period are available from BODC.

Technologically the project was successful in:

i) Establishing the operational use of FerryBox systems

ii) Validating the systems with respect to operability, reliability, and long-term stability

iii) Evaluating commercially available versions of the four core sensors for temperature, salinity, turbidity, and chlorophyll *a* fluorescence

iv) Proving the scientific value of enhanced FerryBox systems for observations of currents and sediment transport (ADCP), pH, oxygen, nutrients and algal species.

Quality control of the data was a key issue. The different sensors were assessed in such a way that reliable comparisons between the data sets are possible.

The scientific value of the detailed near-continuous observations possible with FerryBox systems was proved in studies which:

i) Improved knowledge of the transport of water, particularly in the North Sea and into the English Channel.

ii) Provided a coordinated view of eutrophication and plankton productivity across national boundaries

iii) Used the advanced technology to determine the transport of sediments over long and short spatial and temporal scales

iv) Validated the benefits of regular FerryBox measurements, improving the numerical model through data assimilation and calibration.

v) Demonstrated the mutual benefit of linking remote sensing (satellite) observations with more direct FerryBox measurements.

Throughout the EU FerryBox project the experience was that the costs for the procurement of instrumentation and the sensors and installation costs were relatively low. Standard components are used along with infrastructure already present on the ships (e.g. cable channels, water and energy supplies). The typical investment costs start in the range of 50 000 EUR for fitting the four core sensors and data logging and transmission systems, and then increase as extra sensors are added. Educational outreach installations in the passenger areas cost around 5000 – 10 000 EUR. Operational costs of FerryBox systems need to cover the following activities:

- servicing and maintenance
- calibration and referencing
- system operation and control
- data quality control
- pre- and post-processing
- archiving up to the stage “ready to use for applications”.

The main cost factor is personnel. For the FerryBox project this amounted to 3 to 4 person months/year/system.

2 Introduction

2.1 Background

For several decades ships-of-opportunity such as ferries have been used to collect hydrographic data in coastal and oceanic waters. In the 1930s the Norwegians started to use the Hurtigruten, a ferry line running from Bergen along the Norwegian coast up to Kirkenes, to collect salinity and temperature data on a regular basis. Also in the UK in the mid-thirties Alistair Hardy started his first attempts to collect regular data on the distribution of zooplankton and fish larvae in the North Sea with his newly developed Continuous Plankton Recorder (CPR). These observations are on-going and continue in the North Sea and northern Atlantic Ocean to build the worlds longest biological records (SAHFOS, Annual report 2004).

The starting points of the EU FerryBox project were several developments over the last decade. Reports by EuroGOOS indicated the possibilities of using some of the more than 800 regular ferry lines working in European waters. These could be instrumented with several sensors for the measurement of relevant physical, chemical and biological parameters that were mature enough to be collected operationally (EuroGOOS, 1999; Fischer *et al.*, 2000).

In the Baltic Sea the Finnish Institute for Marine Research took a lead with regular ferry-based observations on the distribution of algal blooms and concentrations of chemical nutrients within the Alg@line project. Alg@line gives warnings on (toxic) algal blooms in the Finnish Gulf and the wider Baltic Sea (Rantajärvi, 2003). The frequent measurements are used to monitor long term changes in the eutrophication status, which are reported in the environmental assessments for the Helsinki Commission (HELCOM).

In Europe the planning of the European Water Framework Directive (WFD, 1999) asked for initiatives to improve and consolidate current monitoring activities in European waters.

In the global context the strategy paper of the UNESCO for the implementation of a coastal module of the Global Observation System (GOOS) requires an observing system comparable with the World Weather Watch even though it will be much more complex (UNESCO 2005).

Thus a clear need exists to improve our observational capacities; not only on standard physical parameters such as temperature and salinity, but also on chemical (nutrients) and biological (phytoplankton, zoo-plankton) parameters This would help the detection of trends of ecosystem parameters in coastal and shelf seas. It could be used for the validation and calibration of models and could be linked to observations by satellites or aircraft (remote sensing) to reveal spatial scales of phenomena. Thus both spatial and temporal scales of marine processes can be better resolved and understood. Most importantly it could provide the detailed, regular, unaliased data needed to enable assessment of the effects of climate change on ocean and coastal environments.

2.2 Objectives of the FerryBox project

The objectives in this project were both technological and scientific (Petersen *et al.*, 2005).

Technological objectives

- Operational use of FerryBox systems on nine ferry routes across Europe for at least one year.
- Comparison of different flow-through systems (FerryBoxes) with respect to operability, reliability, and long-term stability.
- Testing and comparison of different commercially available standard sensors for temperature, salinity, turbidity, and chlorophyll *a* fluorescence on each route.
- Trialing of non-standard sensors in specific FerryBox systems for observations of currents and sediment transport (ADCP), pH, oxygen, nutrients and algal species.

Quality Control of the data was a key issue. The different sensors, manufactured by different companies, were assessed in such a way that a reliable comparison between the data sets was possible.

Scientific objectives

Differences between European coastal and shelf waters should be characterised on the basis of the parameters measured. By selecting different water bodies along the European continent, different water types, ranging from enclosed systems like the

Baltic Sea, to tidally influenced waters like the Wadden Sea, to shelf and coastal seas like the Irish Sea and North Sea and the deep ocean waters of the Bay of Biscay and the Mediterranean, were covered. The major scientific issues of the project were to investigate:

- eutrophication processes
- stability and transport of water masses
- transport of sediments

Secondary scientific objectives were strongly linked to the application of FerryBox data in numerical (ecosystem) models and remote sensing of the sea surface.

All chosen FerryBox routes were connected to end-users who used the products of the FerryBox project. The cooperation with companies enabled further technological developments as well as an improved dissemination of the results.

The scientific aims were studied in detail in the following tasks:

- Linking eutrophication, including plankton productivity and variability in productivity, to physical and bio-geochemical constraints.
- Testing the assessment of the transport of water masses, in the Mediterranean, Baltic Seas, the Western European shelf and its adjacent waters, based on FerryBox data.
- Determining the transport of sediments (and associated contaminants) over long and short spatial and temporal scales.
- Testing the benefits of incorporating FerryBox data into (ecological) numerical models through the assimilation of FerryBox data.
- Validating of remote sensing (satellite) observation against *in situ* FerryBox measurements.

To reach these objectives the following activities were carried out:

- Inter-calibration and comparison of available FerryBox systems, on 9 routes.
- Collection of a uniformly formatted database from all the systems to prove the applicability, reliability and operability of such systems in different European waters.
- Provision of the database to end-users by modern dissemination techniques along with full quality control and metadata information.
- Derivation of relevant information required for monitoring, assessment and scientific understanding by data analysis and modelling.
- Provision to the end-user community of standards, operational guidelines, technical requirements, recommendations and cost-benefit estimates regarding the application of FerryBox systems.
- Creation of public awareness of matters concerning the sea by displaying FerryBox data and related information in an interesting manner through a website and on board ferries.
- Provision, validation and ground-truth measurements for remote sensing applications, in particular data input to the EU projects REVAMP and DISMAR, and to the ESA validation project VAMP.

Thus we aimed to prove the validity of the hypotheses that the FerryBox system can:

- Cost-effectively deliver continuous information of immediate scientific value
- Be a reliable system for monitoring and management
- Provide real-time data that can be effectively assimilated into prognostic numerical models to improve their accuracy.

3 FerryBox System

3.1 Principle design, technical details and installation

A FerryBox as defined in this project is an autonomous measurement and data logging and transmission system which operates continuously while the carrying ship is underway. Measurements are made using devices which are either in direct contact with or sample from a continuous flow of seawater. The principles of such a flow-through system are schematically shown in Figure 1. For an unattended operation the system is controlled via position (by GPS) and an internal computer. The system is connected to a station on shore, via GSM or satellite, for remote control and data transfer. The data transfer is in real time (in case of a satellite connection) or near real time after completion of a cruise in the harbour (within hours or days depending on the length of the route).

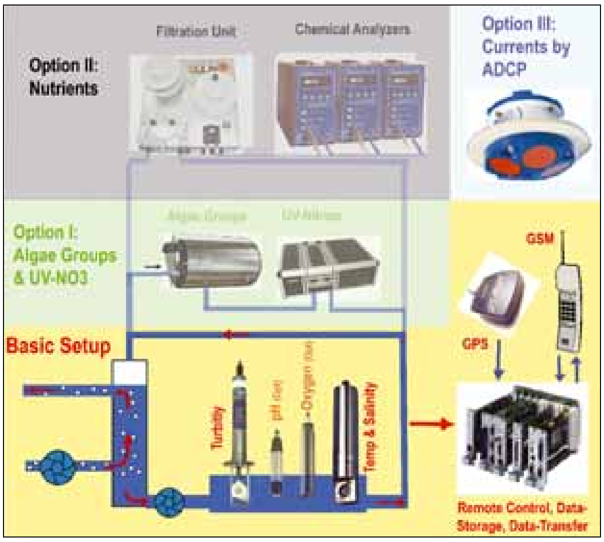

Figure 1 *Principle design of a flow-through system of a FerryBox including available options.*

The water intake is at a fixed depth, normally between 1 and 6 metres. Either a separate water intake point or a sully from one of the internal water flows of the ship can be used. The seawater is pumped into the ship from an inlet (often in front of the ship’s cooling water intake). The FerryBox should be placed as close as possible to the intake point in order to minimise the time delay between water input and signal detection in the FerryBox. The flow rate depends on the system and varies between 3 and 25 l/min. A debubbling unit (not used on all systems) removes air bubbles, which may enter the system during heavy seas. Small bubbles may interfere with some of the sensors (e.g. optical sensors) and may bias the measurements. Coupled to the debubbler is an internal water loop in which the water is circulated passing the different sensors. The basic sensors used are turbidity, temperature & salinity and chlorophyll *a* fluorescence. In some cases an oxygen sensor (Clark electrode or oxygen optode®) and pH sensors were applied as well. The basic setup was extended to further non-standard sensors such as an optical nitrate sensor and an algal group detector (option I on the route in the North Sea) as well as chemical analysers for nutrients (option II). In this case the water had to be filtered before analysis in order to measure only the dissolved nutrient fraction. One FerryBox (Den Helder–Texel) was operated with an ADCP (option III) in order to observe water current velocities as well as sediment transport in a tidal inlet. In some systems an automatic refrigerated water sampler was installed in order to collect seawater at predefined positions for subsequent laboratory analysis (nutrients, phytoplankton composition).

3.2 Routes and installed systems within the FerryBox project

At the start of the project, systems were already in place on ferries in

i) The Baltic Sea between Helsinki and Travemünde and between Helsinki and Tallinn

ii) The Skagerrak, between Hirtshals and Oslo

iii) The North Sea between Hamburg (later on from Cuxhaven) and Harwich in the UK

iv) The English Channel, Celtic Sea and Atlantic Ocean, between Portsmouth and Bilbao

and on two short routes in

v) The Wadden Sea between Den Helder and Texel

vi) The Solent between Southampton and the Isle of Wight.

During the project new Ferryboxes were installed on ferries in the Mediterranean Sea and in the Irish Sea. Figure 2 shows the routes on a map and Figure 3 shows photographs of the different ships used. Table 1 gives an overview of the systems installed on each ferry.

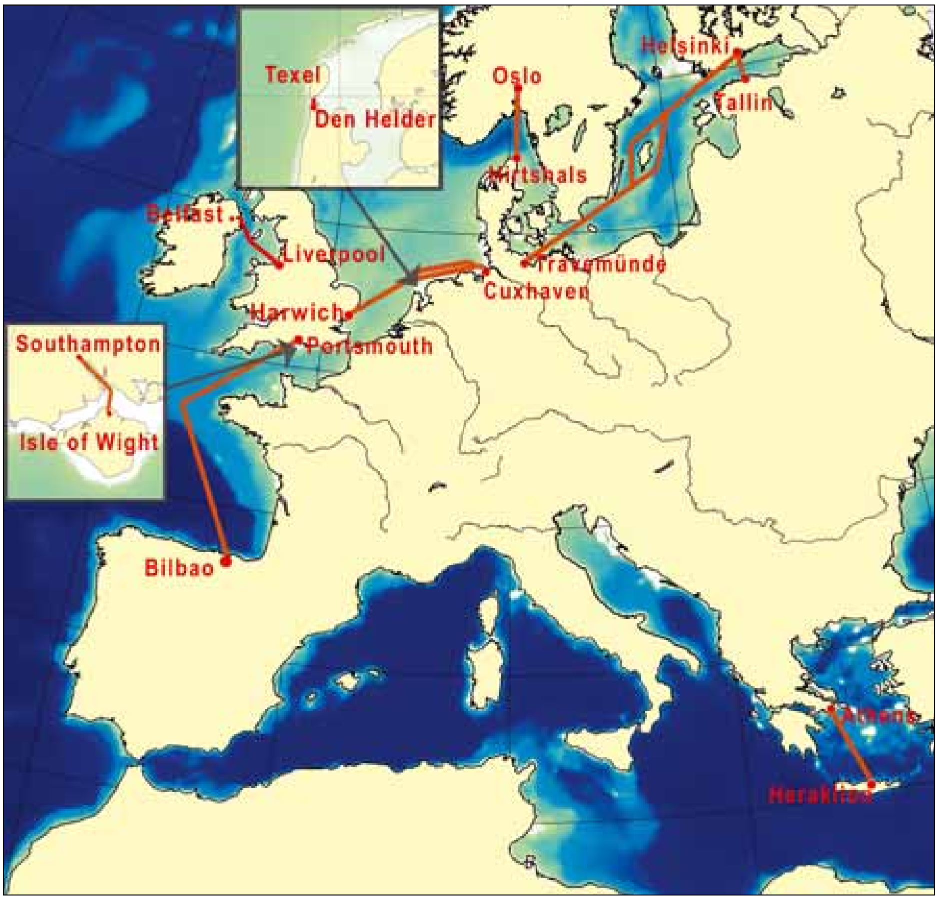

Figure 2 *Map of Ferry routes used in the EU funded FerryBox project.*

Figure 3 *Ferries used in the project*

Table 1 *Overview of FerryBox systems on European ferries*

Area	Route	Observed parameters	Frequency	Period of operation
Baltic Sea	Helsinki (FI)–Travemünde (D)	Temperature, salinity, Chl-*a* fluorescence, nutrients	Daily	1998–today, year round
	Helsinki (FI)–Tallinn (EE)	Temperature, salinity, Chl-*a* fluorescence, nutrients (weekly from water samples)	Daily	1998– today, year round except during ice covered periods
Skagerrak	Oslo (N)–Hirtshals (DK)	Temperature, salinity, turbidity, Chl-*a* fluorescence, nutrients (weekly from water samples), PAR (partly)	Twice daily	Aug 2001–today, year round
North Sea	Cuxhaven (D)–Harwich (UK)	Temperature, salinity, turbidity, Chl-*a* fluorescence, DO, pH, algal groups, nutrients	6–7 times per week	Sep 2003–Oct 2005, year round[a]
Wadden Sea	Den Helder–Texel (NL)	Temperature, salinity, Chl-*a* fluorescence, water currents & sediment transport (ADCP)	28 times per day	1999–Dec 2004, year round[b]
Irish Sea	Birkenhead (UK)–Belfast (UK)	Temperature, salinity, (turbidity, Chl-*a* fluorescence)	Daily	Jan 2004–today[c]
Solent	Southampton–Isle of Wight (UK)	Temperature, salinity, turbidity, Chl-*a* fluorescence	Several times per day	Apr 1999–Nov 2004[d] from spring to autumn
Atlantic, Bay of Biscay	Portsmouth (UK)–Bilbao (ES)	Temperature, salinity, Chl-*a* fluorescence, DO from 2005, pCO2 from 2006	Twice a week (3 day journey)	Apr 2002–today
Aegean Sea	Athens–Heraklion (GR)	Temperature, salinity, turbidity, Chl-*a* fluorescence	Daily	Nov 2003–Nov 2004[e]

a. Ferry route out of service since November 2005
b. Out of operation in 2005 due to delayed start of a new build ferry with a moon pool
c. Route changed to Birkenhead–Dublin in 2006
d. Out of operation since Nov 2004 due to lack of supplementary funding
e. Out of operation in 2004 due to shifting of the ferry-boat to another line

All FerryBox systems reached an operational status by January 2004. Serious problems with low yield of reliable data for the first FerryBox year (from November 2003 to October 2004) occurred on both the new Ferrybox installations for various reasons.

Detailed descriptions of the different systems and their functionalities have been documented in deliverable D-2-1 (Report on the functionality on the FerryBox systems) in the EU FerryBox project reports, www.ferrybox.org.

3.3 Standard sensor set

The standard parameter set which was mandatory on all nine FerryBox systems consisted of sensors for water temperature, salinity, Chl-*a* fluorescence and turbidity.

In most cases the sensors for temperature and salinity operated without major problems. In many systems an offset of the water temperature was observed due to warming up of the incoming seawater in the tubes within the ship and by the pumps. Temperature offsets of 0.5–1 °C were reported. In order to circumvent this, an additional temperature sensor as close as possible to the inlet or on the ship hull is recommended.

The salinity sensor requires a high accuracy and long-term stability, for instance to discriminate between different water masses which differ only little in salinity (<0.1). The experiences with salinity sensors were varied. Some devices were stable over a long time period using the factory calibration only and other devices had to be recalibrated from time to time or revealed shifts in the calibration against bottle salinity data. For devices measuring the conductivity inductively the housing proved to be critical. Small changes of the housing volume caused large changes (salinity>1) in the calibration factor especially for sensors not specially adapted for flow-through systems.

For optical turbidity measurements it turned out that the signal is very sensitive to biofouling. Most of the systems ran with manual cleaning of the system but a wiper on the sensor windows effectively reduces the biofouling problems. In some systems, the interference of small air bubbles made it difficult to measure turbidity accurately at very low values. These small air bubbles even occurred when using a debubbler device in front of the system. The systems used in the FerryBox are based on measuring the scattered light and calibration against Formazin solutions. To get the total suspended matter (TSM) the TSM/turbidity ratio has to be measured by water samples. In the case of the FerryBox line in the Skagerrak it was found that this ratio was constant for the considered transect. Thus the sensor turbidity could be converted to TSM just by a simple conversion factor. At the end of the project reliable turbidity measurements were only available for the routes in the Skagerrak and in the North Sea.

Direct Chl-*a* fluorescence data are difficult to interpret due to the dependence of the fluorescence yield on the pre-illumination, species and photo-physiology of the plankton. Calibrations with measurements of extracted chlorophyll showed that the fluorescence to chlorophyll ratio varies up to one order of magnitude depending on location and time of the year. To get reliable chlorophyll data, regular calibrations of the fluorescence signal have to be carried out against laboratory (HPLC or spectro-photometry) Chl-*a* measurements. This was done intensively on the routes in the Baltic Sea and in the Skagerrak.

3.3.1 Availability of data from standard sensors

On all FerryBoxes the availability of reliable data related to the number of cruises has been estimated on a monthly basis. As an example the availability of the FerryBox data in the Skagerrak in 2004 is shown in Figure 4.

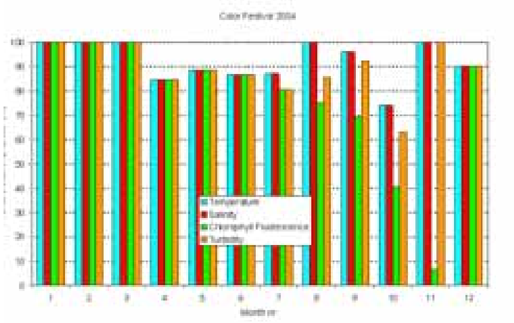

Figure 4 *Plot of the availability of reliable data for the Norwegian ferry route in 2004*

On average the recovered reliable data are 93% for temperature and salinity, 90% for turbidity and 85% for Chl-*a* fluorescence. At the end of the year (Sep−Nov) more problems occurred with bio-fouling on the fluorescence sensor. The experiences after the two to three years of operation on all ferry lines demonstrated that this high recovery of reliable data can only be achieved by regular maintenance of the system and by at least weekly (preferably daily) visual inspection of the data in order to intervene immediately if the data indicate irregular behaviour of the system or of a specific sensor.

The experiences from the different FerryBox systems are documented in more detail in deliverable D-2-3 (Report on the experiences with the FerryBox system, EU FerryBox project report, www.ferrybox.org).

3.4 Extended sensor set

In addition to standard sensors other instruments for the measurement of water currents and sediment transport as well as for chemical properties (nutrients, oxygen and pH) and algal groups were tested on certain ferry lines. A detailed description of the experiences and the suitability of the non-standard sensors can be found in deliverable D-2-4 (Report on non-standard sensor trials, EU FerryBox project report, www.ferrybox.org).

On the route between Den Helder and the island of Texel it could be shown that an ADCP mounted under the keel of the ship is an effective tool to monitor water and sediment transport through channels/straits.

For the assessment of the water quality and for the investigation of biological processes in the water it turned out that measurements of the nutrients as well as oxygen and pH could be achieved. Onboard the ferry in the Southern North Sea chemical nutrient analysers and in addition an *in situ* nitrate sensor (UV detection) were tested. The wet-chemical analysers required a high effort on maintenance in order to get accurate data. The UV nitrate sensor needed lower maintenance but the higher detection limits makes this sensor less suitable for the open sea.

For a better understanding of eutrophication and the underlying processes additional information obtained by nutrient, oxygen and pH measurements are of high scientific value. The new optodes® for oxygen measurement and a Clark-type oxygen sensor when cleaned regularly were stable over long time periods in such flow-through systems. However, for pH the available glass electrode measurements still suffer from insufficient accuracy. One finding was that these improved oxygen measurements together with pH data may provide a more reliable indicator of plankton production than is possible by fluorescence detection alone (Bargeron *et al*., 2006).

For a better characterisation of algae (species, productivity) a new device for algal group detection (AOA, from bbe-moldaenke) as well as a fast repetition rate fluorometer (FRRF, from CTG) for *in situ* measurements of photosynthetic characteristics of phytoplankton were tested. The AOA only gives semi-quantitative data of the algal groups. However the data give indications of changes in the algal species. This information can be used for a specific water sampling and subsequent laboratory analysis (e.g. cell counting etc.). The FRRF to measure plankton photo-physiological parameters and to estimate biological productivity was tested only for a short period, however the complexity of the data suggests that it should not be considered for routine analysis.

On the routes in the Skagerrak, the Baltic and the North Sea automatic water samplers have been used with success in order to get reference samples. These samples are processed in the laboratory to both calibrate the on-board sensors and to study phytoplankton species and other constituents in more detail.

3.5 Problems with biofouling

For high reliability of the data and long-term stability of a FerryBox system the problem of biofouling has to be solved. Sometimes this leads to problems with all the basic sensors including conductivity and temperature. Although it was an anticipated problem the timing of the most severe impact of biofouling distorting the sensor signal was difficult to predict. Long-term experiences revealed that for long periods the biofouling may be negligible while at certain times biofouling with a strong impact on the measured data occurs within one week or even several days. It was different between routes and surprisingly different between different years in the same area.

The biofouling problems can only be avoided by frequent cleaning of the system, in particular at times of high biological activity. This can be achieved either by regular manual cleaning of the system or by implementation of effective automatic cleaning procedures. Most of the FerryBox systems were manually cleaned. However in the North Sea an automatic self-cleaning system was implemented. It prevents biofouling by cleaning specific sensors with tap water under high flow and rinsing the whole system with acidified water after each cruise. This was found to prolong the periods between the need for manual maintenance, and drastically improved the long-term reliability of the data. By these measures the long-term stability of sensors such as salinity could be prolonged up to one year without maintenance and manual cleaning. This self-cleaning principle was also implemented in the industrial version of the FerryBox (Figure 5) operated in the Mediterranean Sea.

Figure 5 *Industrial version of a FerryBox (4H-Jena, Germany)*

3.6 Data management and on-line data service

On all FerryBoxes the data were logged on a data logger onboard. In addition data could be sent to shore in real time (with 5–10 minute time intervals where there is a satellite connection) or when the ferry has reached a harbour (for a GSM connection). In some cases on-shore data are automatically transferred to a database. As an example Figure 6 shows the data-handling procedure of the FerryBox in the North Sea.

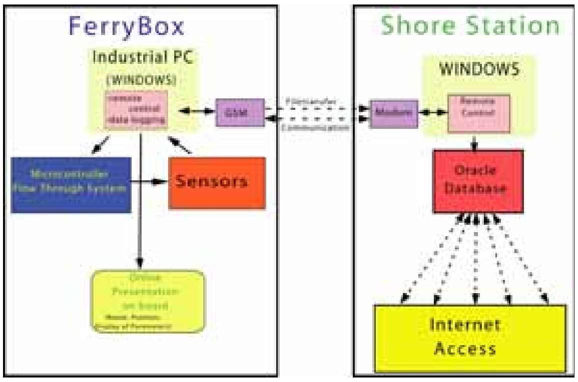

Figure 6 *Data handling on the ferry in the North Sea*

During the project all operators of FerryBox systems established individual websites, web pages, data retrieval and/or public information services for their individual system applications. As an example the website from the North Sea ferry is shown in Figure 7. GKSS operates an on-line database for their FerryBox data. Users can generate graphs and registered ones can also extract numerical data (ferrydata.gkss.de).

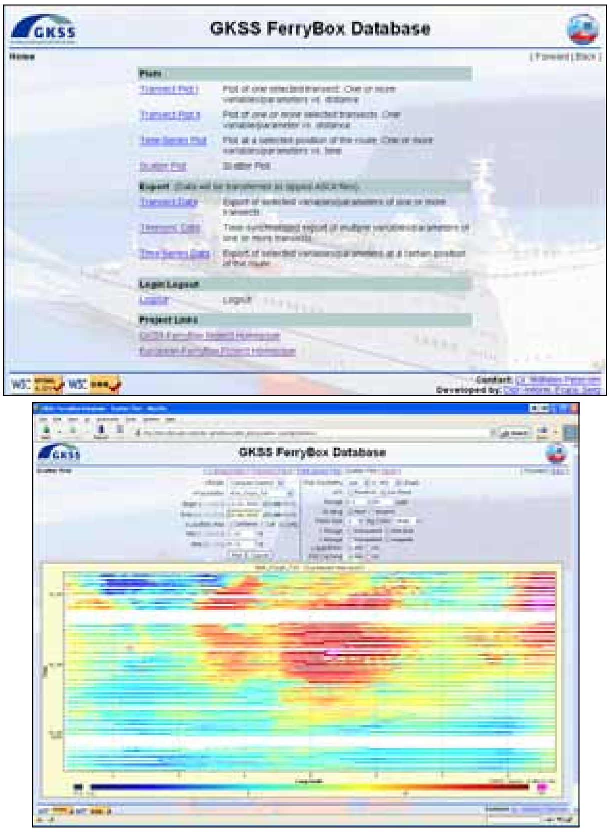

Figure 7 *Website of the North Sea FerryBox data and graphical presentation of Chl-a along the transect in spring 2005 (coloured scatter plot)*

The National Oceanography Centre (NERC.NOC) established dynamic FerryBox web pages and data services which provide information on the FerryBox systems operated by the centre. Users can view graphs and animations, generate data plots and also retrieve track information (Figure 8). Quasi-real-time and raw numerical data can be extracted from an on-line database without access restrictions. (www.noc.soton.ac.uk/ops/ferrybox_index.php)

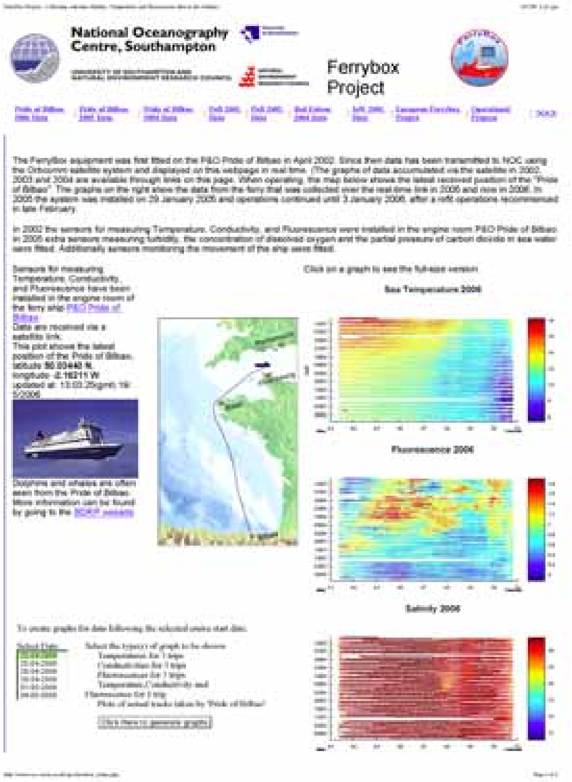

Figure 8 *FerryBox website of National Oceanography Centre (NERC.NOC)*

The Norwegian Institute for Water Research (NIVA) runs a series of web pages providing information about their different FerryBox applications and routes including the Oslo–Hirtshals route which contributed directly to the FerryBox project. On the title page of each ferry route further information and data are provided. For three routes it is possible to retrieve real time information on the ferry position as well as the latest data and status information through a broad band satellite link directly from the ferries. On-line services for data retrieval are established for users (www.ferrybox.no).

Passengers are able to view an on-line display presenting FerryBox data and other interesting information during the trip, with the system that was developed and implemented on the Dutch ferry between Den Helder (www.nioz.nl/) and the island of Texel. This has enabled a large public community to gain insight into water current speed and direction, water temperature, salinity and phytoplankton density. The system includes pages explaining how and why the data is being collected. This contributes to the general understanding of the sea and has proved popular with both the wider public and the ferry operating company (Figure 10). The NIOZ helped NOC set up a similar system on the Portsmouth–Bilbao route which has also been well-received by the passengers and ferry operator.

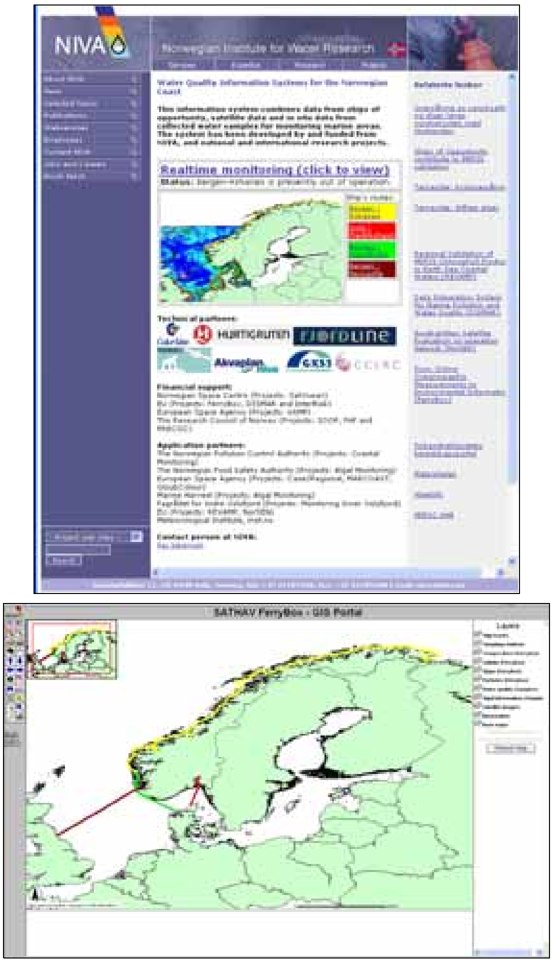

Figure 9 *Website of the North Sea FerryBox data and graphical presentation of coloured track plots*

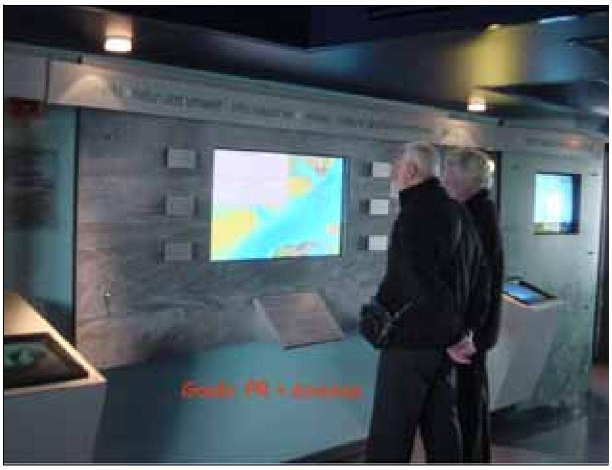

Figure 10 *Example of on-line display presenting FerryBox data on board to the passenger areas (FerryBox between Texel and Den Helder)*

4 Application of FerryBox data for actual environmental problems

4.1 Occurrence of cyanobacteria blooms in the Baltic

The Baltic Sea in northern Europe, is surrounded by 9 countries and approximately 85 million people live in its catchment area. Ecologically the Baltic, which is the biggest brackish water basin in the world, is unique. The low salinity, together with winter ice cover, significantly affects the distribution of aquatic flora and fauna in the Baltic. The seasonality, with changes in colour of the phytoplankton community in the open sea can be perceived even by casual observers. Towards the end of summer some locations suffer from frequent cyanobacterial blooms, with turquoise or green to yellow colours. These summer blooms of nitrogen-fixing filamentous cyanobacteria, with main species *Nodularia spumigena*, *Aphanizomenon sp*, and *Anabaena spp.*, counteract the reduction of anthropogenic nitrogen load by their N-fixing capacity. They have possible toxic effects on biota and so may decrease the yield of fisheries, and affect the recreational use of coastal areas. The intensity of these blooms is related to a low inorganic N:P ratio, high temperature of surface waters, and low wind mixing.

To find out the triggering factors for these blooms and their environmental consequences, phytoplankton dynamics must be studied with the relevant spatial and temporal resolution. This will support science-based management of the Baltic Sea. For this task, in the Finnish Institute of Marine Research, the traditional methods for phytoplankton studies have been supplemented with automated detection systems placed on ships of opportunity, and with satellite data. In the Baltic Sea, the Alg@line system (www.balticseaportal.fi), coordinated by FIMR, for the detection of phytoplankton biomass by fluorescence has been running for 13 years. Alg@line utilises merchant ships and ships of the Finnish coastguard.

Measurement of Chl-*a in vivo* fluorescence is not optimal for the detection of cyanobacteria. In these species fluorescence at the wavelengths specific for chlorophyll is very weak. Instead, these species contain phycobilin pigments that have their own specific wavelengths for excitation and fluorescence emission. From previous studies with pure phytoplankton cultures and experimental work in the field it was established that bloom-forming filamentous species in the Baltic are the main source of phycocyanin-related optical signals.

During the FerryBox project, laboratory tests were conducted with a Turner AU-10 fluorometer with a phycocyanin kit (excitation 620 nm, emission 650 nm). It was verified that sensitivity and linear range are suitable for detection of natural concentrations of filamentous cyanobacteria. A high instrument specificity was found, with the effects of light scattering and overlapping fluorescence from dissolved matter and other pigments being negligible. Phycocyanin fluorescence readings are further normalised to known concentrations of commercially available C-phycocyanin in buffer, as the actual *in vitro* phycobilin concentration measurements are hard to perform from discrete water samples due to its large spatial heterogeneity (Figure 11).

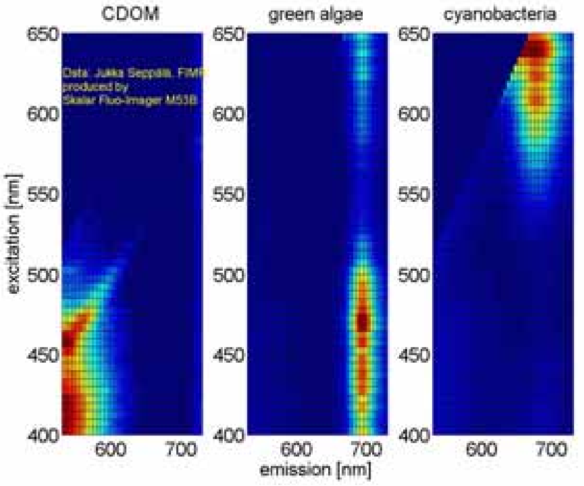

Figure 11 *Excitation–emission matrix for coloured dissolved organic matter (CDOM), and for cultured green algae with high chlorophyll a fluorescence and filamentous cyanobacteria with high phycocyanin fluorescence*

A phycocyanin fluorometer was used for a pre-operational testing phase in summer 2004, on cruises with the RV Aranda. It was operated in flow-through mode together with two fluorometers for chlorophyll detection (AU-10 and Cyclops-7), and a flow-through spectro-fluorometer. Discrete samples were taken from the water flow to determine pigment concentrations, count phytoplankton cells and measure the light absorption by phytoplankton. These data are not yet fully available, but our objective is to obtain estimates on the variability in cyanobacterial biomass and pigment-specific fluorescence intensities for calibration purposes for the phycocyanin fluorometer.

As an example of data collected, the grid recorded in 26–27 June, 2004 in the Gulf of Finland (Baltic Sea) clearly shows the location of cyanobacterial bloom patches, with high phycocyanin fluorescence, in the middle of the cruise grid (Figure 12).

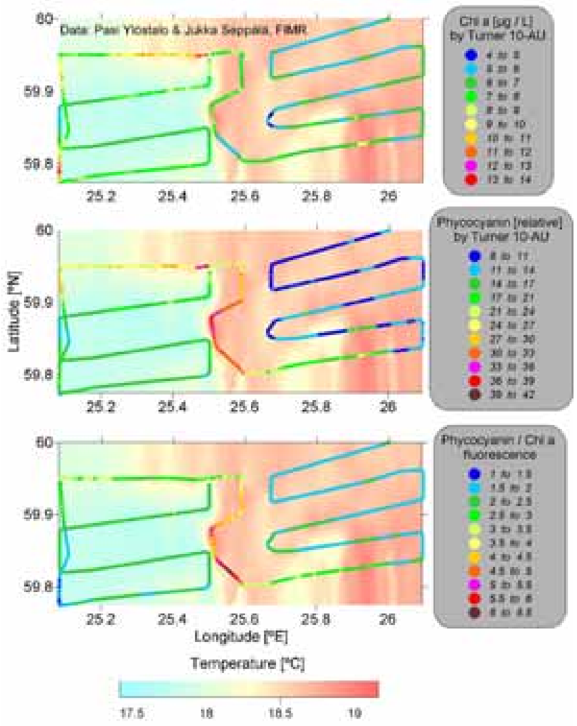

Figure 12 *Spatial variability of Chl-a concentration, phycocyanin fluorescence and their ratio as estimated by two Turner AU-10 fluorometers during a bloom of filamentous cyanobacteria.*

The locations of these high phycocyanin areas are identical to visual observations of bloom areas. Clearly, phycocyanin and chlorophyll fluorescence are not directly related. Obviously, chlorophyll fluorescence mainly reflects the eukaryotic part of the phytoplankton community while phycocyanin fluorescence reflects only filamentous cyanobacteria in our study area.

In 2005 a phycocyanin fluorometer was installed on the Finnpartner ferry and started to record the seasonal phycocyanin transects across the Baltic Sea to evaluate cyanobacteria bloom development (Figure 13). These data is used for validation of ecosystem models, and in validation of ocean colour data for cyanobacterial distribution.

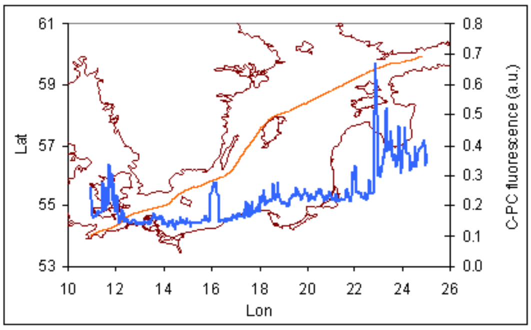

Figure 13 *Amount of blue-green algae in the Baltic Sea 23–25 July 2006. Fluorescence equalling the concentration of phycocyanin (blue-green algal biomass) in the surface layer along the route of the ferry Finnpartner from Travemünde to Helsinki.*

Phytoplankton data collected in the Gulf of Finland reveal the changes in species composition and biomass of three main bloom forming species during bloom periods in years 1997–2004. The integrated biomass of *Aphanizomenon*, *Nodularia* and *Anabaena* over the bloom periods in 1997–2004 is shown in Figure 14.

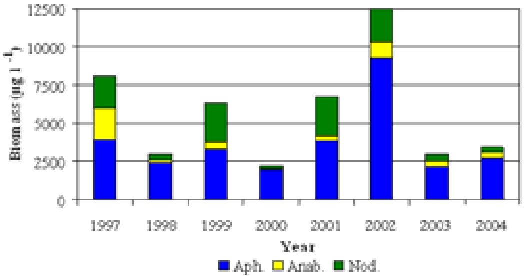

Figure 14 *Integrated biomass of Aphanizomenon, Nodularia and Anabaena over the bloom periods in 1997–2004*

The data collected during 8 successive years show that the most intensive bloom was observed in 2002, mainly due to a very high biomass of *Aphanizomenon*. High biomass of cyanobacteria was also recorded in 1997, 1999 and 2001 but they were low in 1998, 2000, 2003 and 2004. Even though there were no big cyanobacterial blooms in the Gulf of Finland in years 1998, 2000, 2003 and 2004 there was still high biomass of *Aphanizomenon* filaments in the upper water column. The four low biomass years were characterised by very low biomass of potentially toxic *Nodularia* and *Anabaena* species.

4.2 Relations between winter nutrient concentrations and algal blooms in summer

A method for establishing a numerical index (indicator) to summarise annual variations in plankton bloom intensity and duration in different sea areas was tested. Such an index has the potential to be used by organisations such as the European Environment Agency as a management tool. The procedure tested is based on work by FIMR (Fleming and Kaitala, 2006). A simple numerical index is calculated to describe the magnitude of the spring bloom. This is an integration of the variation in concentration of chlorophyll over the spring bloom period in different regions compared to the amounts of nutrients present at the end of the winter.

The key to its use as a management tool is in understanding the degree to which the index can be taken as a measure of eutrophication because it is proportional to the amounts of nutrient present at the end of the winter. Figure 15 shows the spring phytoplankton bloom index against the geometric mean of the maximum winter nutrient concentrations for the Baltic Sea and the Atlantic. A general relationship between a high plankton index and higher concentrations of nutrients does exist. However further work needs to be done to refine the idea. The figure reveals that in the Baltic there is a wide variation in the index and its relationship to concentrations of nutrients from year to year suggesting that a degree of caution should be taken into account when trying to make judgements on the basis of data from a single year. In contrast to the Baltic Sea and the Atlantic such clear relationships could not be observed in the compiled data set for the North Sea transect. This poor relationship may stem from the availability of light and advection controlling biomass rather than simply nutrients in this region.

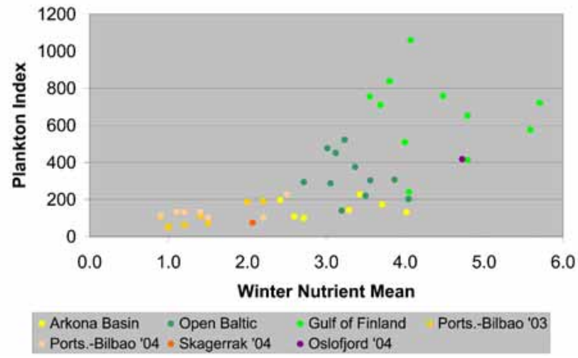

Figure 15 *Plot of the spring phytoplankton bloom index against the geometric mean of the maximum winter nutrient concentrations, for results from the Baltic (Gulf of Finland, Open Baltic and Arkona Basin) in 1992–2004 and Portsmouth to Bilbao in 2003 and 2004.*

FIMR has evaluated the occurrence of cyanobacteria in relation to nutrients and salinity and temperature in the Baltic Sea using Alg@line data along the route Helsinki–Travemünde for the years 1997–2002 (Kaitala *et al*., 2004). This has allowed them to determine specific relationships between

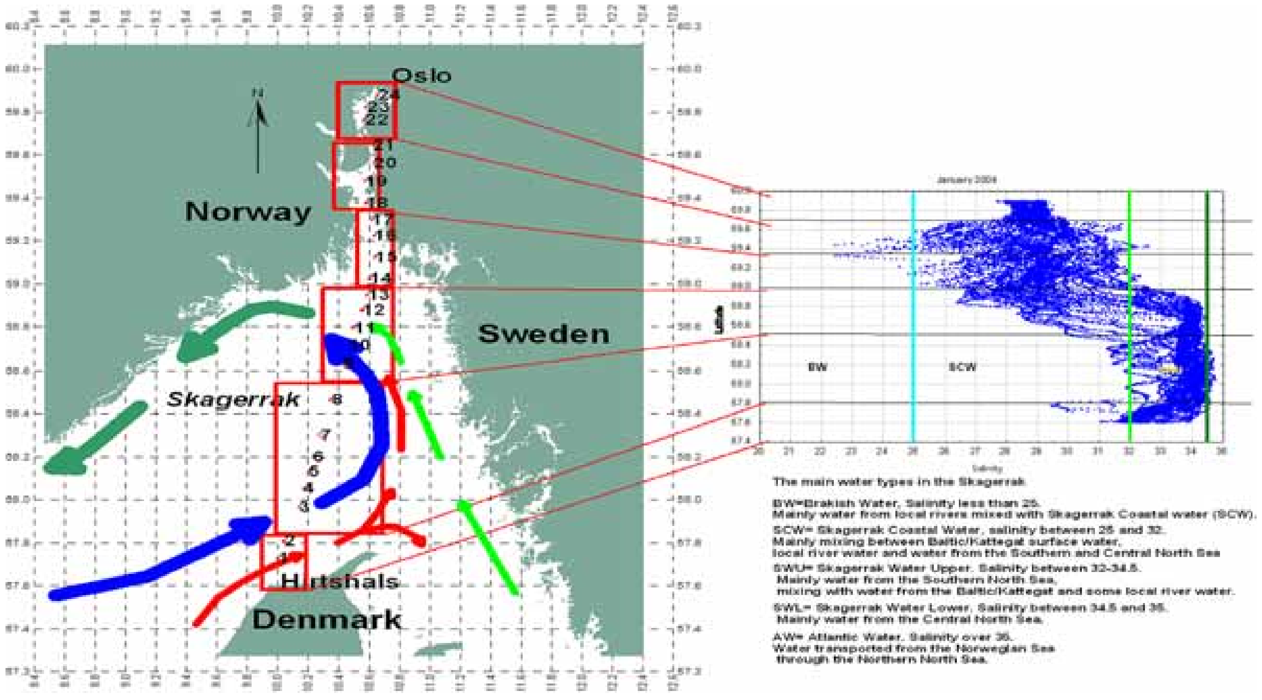

Figure 16 *Classification of different regions in the Skagerrak*

single species and a set of parameters. For example, *Aphanizomenon* tends to dominate at lower temperatures and so is more abundant in spring than *Nodularia*. High abundances tend to be found in spring with a maximum density in the Gulf of Finland in June/July. On the other hand higher summer temperatures over 15ºC and minimum concentrations of phosphate and nitrate are associated with the maximum abundance of *Nodularia*.

4.3 Classification of water masses

Fronts in the water masses impede mixing of waters and may affect sediment transport and enhance productivity. FerryBoxes can determine the variations in water mass properties with high frequency and accuracy.

As an example of how different regions in areas along a FerryBox route may be defined both in terms of FerryBox data and local knowledge, Figure 16 shows the FerryBox route in the Skagerrak (left panel) including existing knowledge of current flow patterns. The flow patterns correspond well with the measured salinity by the FerryBox in January 2004.

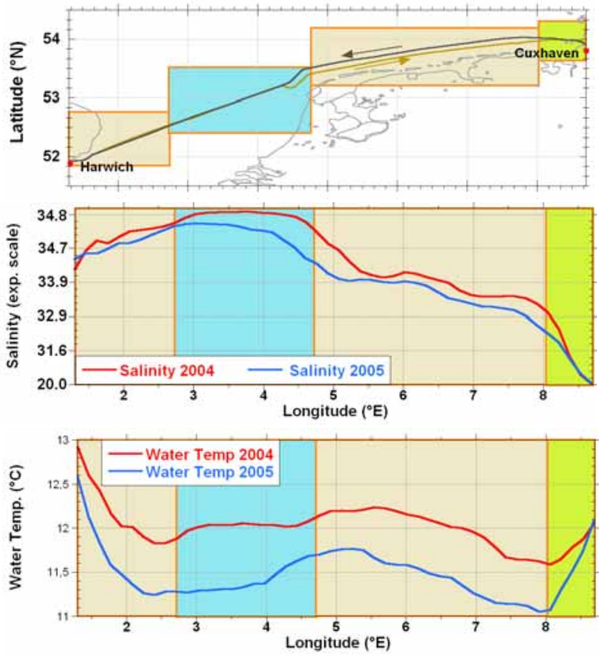

Figure 17 *Classification of the water masses along the transect in the Southern North Sea and comparison of yearly means of salinity, water temperature and Chl-a fluorescence*

Another example depicted in Figure 17 compares the annual data (yearly means from 2004 and 2005) of salinity, water temperature and Chl-*a* fluorescence along the transect in the Southern North Sea, with different regions differentiated by their salinity indicated by boxes. In 2004 slightly higher temperature and salinity values were observed as well as a small eastwards shift of salinity maximum. Also noticeable is the different location and extend of Chl-*a* fluorescence maxima in the two years, which may be partly explained by the somewhat higher water temperatures indicating higher radiation input in 2004.

4.4 Oxygen dynamics in coastal waters

Changes in the concentrations of dissolved oxygen are determined by changes in the temperature of the water and biological production and respiration. The biological changes are relatively large and easily measured while changes due to temperature can by calculated from well established information. As the FerryBox programme was being developed both improved Clark-type electrodes and the newer optode® became available so that oxygen could be measured routinely as part of a FerryBox system. This enabled the project to compare estimates of biological production based on oxygen measurements with the more common use of chlorophyll fluorescence as an indication in changes in phytoplankton biomass.

As an example Figure 18 shows the observations of pH and oxygen together with the Chl-*a* fluorescence along the transect in the Southern North Sea (Cuxhaven–Harwich) in spring 2005. In general the pattern of the three figures looks similar. High algal activity (measured by the Chl-*a* fluorescence) starting along the Dutch coast (between 4.5°E to 6.5°E) in mid-April with a maximum in mid-May and diminishing by the end of May, corresponds well with the pH maxima and the high oxygen oversaturation. Later on, high algal activities are detected in the Elbe estuary in the German Bight (8.2 to 8.7°E). However, when examined in detail the relation of Chl-*a* to pH and oxygen sometimes looks different. For instance in late June in the region influenced by the English Channel (2°E to 3.5°E), high oxygen saturation does not correspond with the chlorophyll fluorescence and pH values at that time. This behaviour may be explained by stratification of the water column and biological production. In the summer, biological production and chlorophyll are located at the thermocline. These waters are too deep to be sampled by the FerryBox. However oxygen produced as the plankton grows diffuses towards the surface and is detected by the FerryBox.

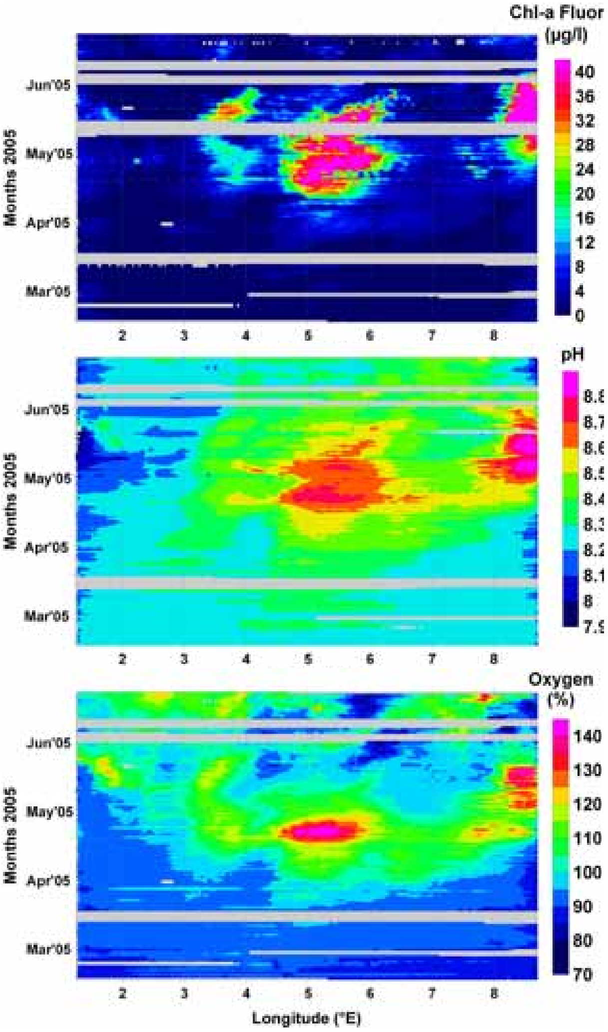

Figure 18 *Chl-a fluorescence, pH and oxygen (saturation index) observations along the transect in the Southern North Sea (Cuxhaven–Harwich) in spring 2005*

To examine this idea fully, measurements of dissolved oxygen were made on the monthly calibration crossings on the Portsmouth Bilbao route between February and July 2004 (Bargeron *et al.*, 2006). The difference between the observed oxygen concentration and the solubility of oxygen at the *in situ* temperature and salinity of the water sample (the oxygen anomaly) was calculated. The anomaly was then used to determine the direction of the oxygen flux across the sea surface. This was used with available wind speed data to estimate the oxygen flux across the sea surface, giving a measure of net community production (Najjar and Keeling, 2000). For the data presented in Table 2, the estimates based on the two of the most commonly used parametrisations of the relationship between gas exchange and wind speed (O_2 W'92; Wanninkhof and McGillis, 1999 and O_2 W&M'99; Wanninkhof, 1992) are presented. These are compared to estimates of production based simply on changes between the sampling crossings in concentrations of the production-related parameters nitrate (dNO_3), oxygen (dO_2) and chlorophyll (dChl). To assess the link between hydrography and production the route was divided into different hydrographic regions:

- CEC (Central English Channel), shallow and tidally well mixed year round
- WEC (Western English Channel), seasonally stratified
- Ush (Ushant frontal area), subject to varying stratification and upwelling
- SB (Shelf break region), steep shelf with occasional upwelling (Pingree and Griffiths, 1978)
- NBB (northern Bay of Biscay), deep water seasonally stratified but influenced by river water
- SBB (southern Bay of Biscay) seasonally intensely stratified and oligotrophic and summer (Lavin *et al.*, in press).

Table 2 *Comparison of estimates of net community production (g C m^{-2}) over the spring–summer period*

Area	**O_2 W'92**	**O_2 W&M'99**	**dNO_3**	**dO_2**	**dChl**
CEC	80	38	19	9	18
WEC	63	33	19	15	19
Ush	119	60	24	17	9
SB	83	41	20	13	13
NBB	67	32	22	14	14
SBB	41	20	13	11	4

In Table 2 the results of the comparison of the estimates of net community production show that only estimates of production based on calculation of the oxygen flux produce estimates of productivity which are in line with existing direct measurements of productivity in these regions, which are in the range 25–90 gC m^{-2} (Joint *et al.*, 2001). In Table 2 the Ushant area shows up clearly as the region of highest productivity, inline with the known higher productivity of frontal regions (Pingree and Griffiths, 1978). The results of tests relating measurements of oxygen concentration demonstrate the potential of being able to use oxygen measurements to derive an estimate of biological production which is potentially more reliable than that which can be obtained from measurements of Chl-*a* fluorescence. Continuous measurements of oxygen using the Aanderaa Optode® are now being tested on the Cuxhaven–Harwich and the Portsmouth–Bilbao routes.

5 Application of FerryBox data for scientific issues

Within the FerryBox project a series of scientific issues were treated. The examples below show the relevance of the FerryBox data in the analysis of ecological and physical processes in the marine environment. These are:

i) The combination of remote sensing data and FerryBox data to provide wider area cover of the observations

ii) The use of hydrographic information obtained from a FerryBox to explain occurrence of exceptional algal blooms

iii) The measurement of sediment transport in tidal inlets by using ADCP

iv) The use of FerryBox data to improve hydrodynamic and ecological models.

5.1 Spatial extension of algal blooms estimated by combining FerryBox data with remote sensing

While FerryBox data can provide good temporal resolution along a defined route, spatial extrapolation of such observations needs to be carried out with caution. This spatial restriction can be overcome by combining with data from other platforms (Petersen *et al.*, 2006). For optically active constituents such as chlorophyll and suspended matter, remote sensed data can be used.

Chl-*a* fluorescence, turbidity and temperature have comparable satellite products of Chl-*a*, total suspended material (TSM) and sea surface temperature (SST), while salinity (SSS) at the moment cannot be measured from space. In the case of Chl-*a* the optical FerryBox sensor data (fluorescence) needs to be converted to the geophysical product Chl-*a* before it is compared to the satellite products. The satellite geophysical products are processed with different coastal and open sea processing algorithms from the measured ocean colour signal. The turbidity FerryBox sensor signal needs to be converted 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 a flow-through FerryBox system sampling water 4–6 metres below the surface needs to be considered.

Figure 19 shows, as an example, the spatial distribution of Chl-*a* concentration derived from ENVISAT–MERIS (algal-2 for case-2 water) for the North Sea in May 2005 and the chlorophyll fluorescence, dissolved oxygen (DO) and pH along the track measured by the FerryBox on the same day that the satellite image was recorded. From the image the spatial extent of the algal bloom in the English Channel region (3.3°E–4.2°E) can be clearly seen. The bloom along the Dutch coast (4.8°E–6.5°E) began in April and was already diminishing in May as evidenced by the increased patchiness. The activity of the algal bloom is also reflected by DO concentration along the track. High over-saturation of oxygen indicates photosynthetically active blooms in the English Channel and in the Elbe estuary (8°E–8.7°E). In contrast, along the Dutch coast the oxygen levels are lower possibly due to oxygen consumption (DO 90–100%) and indicative of a collapse of the bloom in this region.

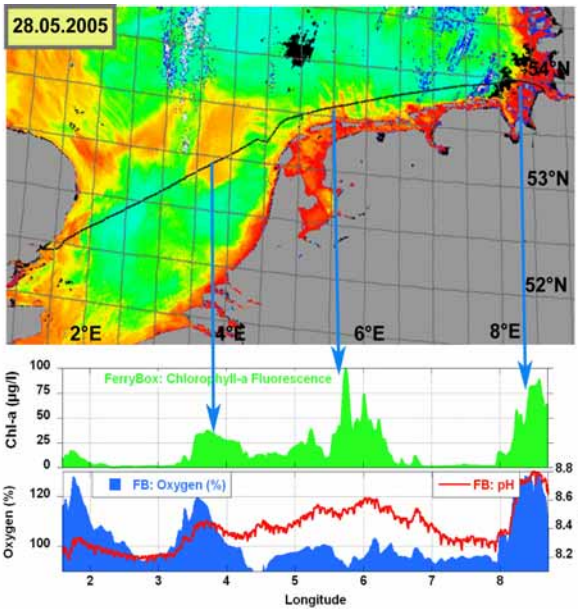

Figure 19 *Chl-a concentration derived from ENVISAT–MERIS (algal-2 for case-2 water) for the North Sea and comparison with Chl-a fluorescence, oxygen saturation index and pH along the track of the ferry (black line) on 28 May 2005*

This example demonstrates the way in which combining data from different platforms, with different spatial and temporal characteristics, enables us to improve the overall picture of the environmental state. Clearly, there are times when observations are not available from one platform, for example, when clouds interfere with ocean colour measurements.

5.2 Ground truth data from FerryBox data to validate satellite data

On the other hand remote sensed data can profit from FerryBox data due to its high measuring frequency in coastal and remote areas delivering ground truth data.

Some of the FerryBox systems have the possibilities to collect water samples from the flow-through system and from these samples the Chl-*a* and TSM can be analysed in the laboratory delivering calibration data to convert the Chl-*a* fluorescence to real Chl-*a* values. The problem of using one single subsurface depth needs to be considered, but since the satellite products are based on an ocean colour signal which is backscattered over several metres of water depth, the effect of the thin surface is not so predominant as it is for SST.

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 Chl-*a* can be high. To explore this variability between the FerryBox partners a Chl-*a* intercomparison was arranged, between the partners and some other invited laboratories. The results showed that deviation between even trained laboratories can be up to 20%. More results are found in deliverable D5-4, Report on the use or FerryBox data for validation purposes of satellite data, EU FerryBox project report (www.ferrybox.org).

Chl-*a* fluorescence measured *in vivo* or *in situ* is strongly coupled to the biochemistry of the phytoplankton and diurnal as well as seasonal variation is frequently seen. These variations must be taken into consideration, when measuring Chl-*a* in a FerryBox for validation of the geophysical satellite products. This was investigated by comparing Chl-*a* analysed from water samples by HPLC with the Chl-*a* fluorescence signal. For some areas as in the Skagerrak where the ferry covered the same track both night and day the variation in the Chl-*a* fluorescence/Chl-*a* could be up to a factor 2. For other areas such a large variation was not seen, but the seasonal variation was more predominant. Figure 20 shows the averaged Chl-*a* fluorescence/Chl-*a* ratio between January and June 2004 in the Skagerrak. Nevertheless this variation needs to be considered when fluorescence data are to be used for validation of the geophysical Chl-*a* product. In order to get real Chl-*a* values the Chl-*a* fluorescence data have to be converted by these ratios during the bloom periods on at least a weekly basis.

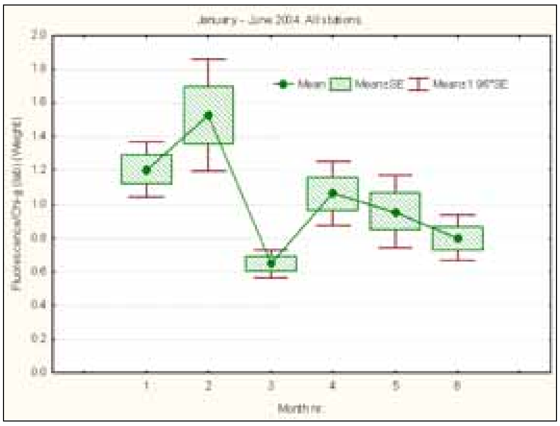

Figure 20 *Variation in Chl-a fluorescence/Chl-a ratio between January and June 2004 in the Skagerrak.*

5.3 Intrusion of French river water into the English Channel and subsequent algal blooms

In several areas FerryBox data provided evidence of enhanced blooms that could be related to specific physical processes such as freshwater inflows. In the Bay of Biscay and English Channel it has been possible to link bloom activity to specific hydrographic features (Kelly–Gerreyn *et al*., 2006). Figure 21 shows observations made by the NOC Portsmouth to Bilbao FerryBox of an intense monospecific bloom (~100 mg Chl-*a* m^{-3}) of the dinoflagellate *Karenia mikimotoi* in the western English Channel in summer 2003. The onset of the bloom in 2003 occurred within 2 days of the arrival of low salinity (<35) waters (Figure 22) originating from French Atlantic rivers (Loire and Gironde). The hypothesis is that the low salinity intrusions with higher concentration of nutrients enhance blooms of *K. mikimotoi* through increased buoyancy of the upper water column and thereby influence the observed inter-annual variability in the abundance of this phytoplankton in the western English Channel.

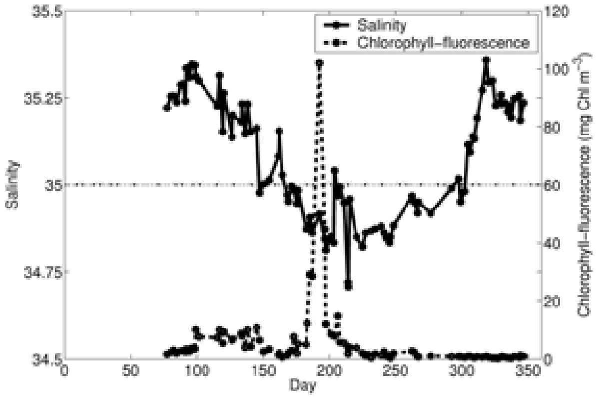

Figure 21 *Time series data of chlorophyll fluorescence and salinity showing the coincidence in the timing of the bloom in Karenia mikimotoi and the arrival of low salinity water in the western English Channel (49.1°N, 4.1°W) in 2003*

The detailed time series from the FerryBox were used to verify this hypothesis for the first time, that French Atlantic coast rivers are a major source of lower salinity waters which are frequently observed in the English Channel in summer and may be connected to the enhanced growth of nuisance algae in some years.

The FerryBox data provide information to improve the understanding of:

i) fronts limiting mixing of waters and enhancing productivity

ii) movements of the fronts.

This can be seen in Figure 22. The frequent FerryBox measurements enable detection of the movement of fresher water (and associate fronts) from the French Atlantic coast into the English Channel.

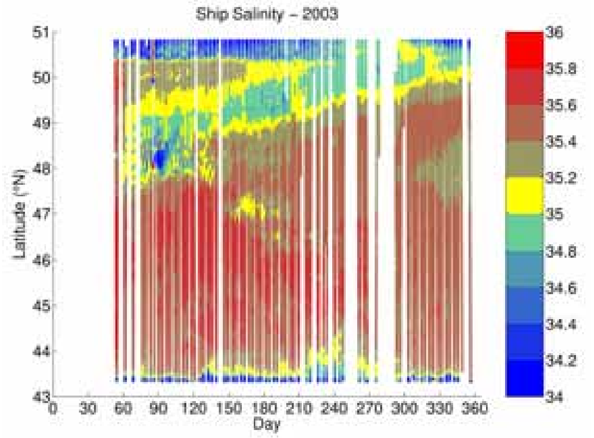

Figure 22 *Sea surface salinity between Portsmouth and Bilbao in 2003 showing timing of the progress of low salinity waters into the western English Channel.*

5.4 Sediment transport estimated by ADCP measurements in a tidal inlet

The ferry from Texel to Den Helder across the Marsdiep tidal inlet (the northern coast of the Netherlands) is equipped with a vessel-mounted ADCP. The instrument is attached to the hull of the ferry 30 cm below the hull itself to prevent problems with air bubbles and interference with the turbulence of the ship. This technique measures the current field below the moving ferry. The technical quality of the observations appears to be good.

Most of the scientific work done in this task was carried out by NIOZ. This group is the only FerryBox project partner working on the application of ADCP based methods to determine sediment transport.

Observations on currents and backscatter are used to obtain insight in the current field and suspended sediment concentration in the tidal inlet that forms the connection between the western-most tidal basin of the Wadden Sea and the adjacent North Sea. The long duration and, especially, the high frequency of the observations (the ferry crosses the inlet every 30 minutes each day between 06.00 and 22.00 h) make the observations suitable for such studies.

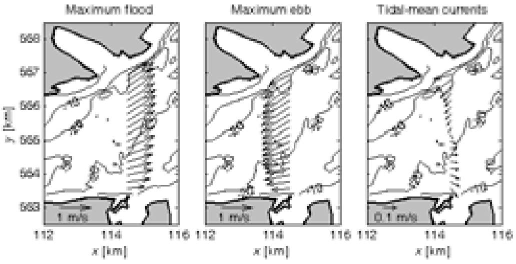

Figure 23 *Typical examples of the depth-averaged tidal and mean currents in the Marsdiep inlet as observed with the ferry-ADCP on the route Den Helder to Texel*

The results obtained by the NIOZ FerryBox give an excellent demonstration of what ships-of-opportunity systems can achieve in terms of the precision in the data delivered by the continuous repetition of their tracks by ferries. Figure 23 shows typical examples of the depth-averaged currents around maximum flood, maximum ebb and of the tidally averaged currents. The precision of the data allows both peaks and troughs in flow to be identified both in time and location. Tidal currents reach maximum values of around 1.5 m s^{-1}, with strongest currents in the deepest central part of the inlet. The strength of the tidally averaged currents (residuals) is about

10% of the maximum tidal currents and has a large spatial variability even over the relatively short distance of the inlet (about 4 km). At the northern side of the inlet the mean currents are outward (towards the adjacent North Sea), at the southern side the currents are inward. The influence of wind or river inflow on these tidal mean currents appears to be relatively weak because they are mainly caused by the interaction between the tidal currents and the topography.

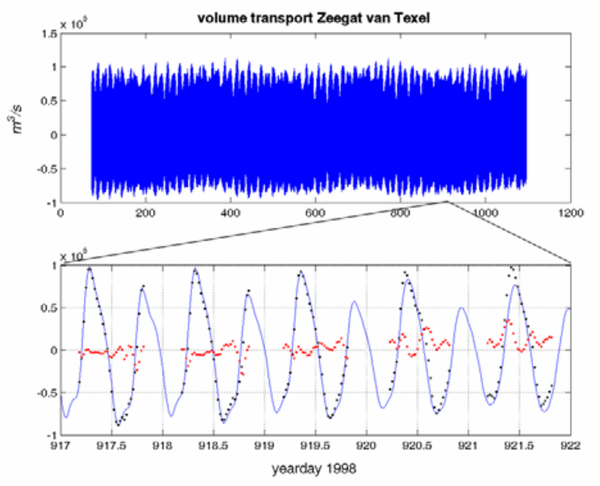

Figure 24 *Water transport through the Marsdiep tidal inlet between the North Sea and Wadden Sea as determined from the long term ADCP observations. The top panel shows the harmonic fit to the data for a period of about 4 years, the bottom panel shows a typical example of the original data (black dots), the harmonic fit (blue line) and the difference between both for a period of 6 days.*

By integrating the measured vertical profiles over each transect (which takes 12–15 minutes) a more-or-less synoptic dataset on the water transport through the entire inlet was obtained. A harmonic fit, using 67 tidal components, was applied to analyse this data set. Figure 24 shows the results for a period of 5 years (1998–2002) of observations. The upper panel of the figure shows the harmonic fit of the data and the bottom shows the original data (black dots), the harmonic fit (blue line) and the difference between both (red dots) for a representative number of days. Further analyses showed that the variability in the remaining signal (red dots) can largely be explained from variability in the wind speed and direction. For such an analysis of the variability in the water transport it is essential that the data set has both a high frequency and a long duration enabling the determination of relatively high and low frequency tidal components. Here the period of the tidal components that was used in the analysis varied between some hours and about one year.

This information on transport is essential for identifying the forces transporting suspended sediment. The ADCP data also provide information on sediment loads. The NIOZ studies found problems with the model commonly used to relate backscatter to suspended sediment concentration. A new model was developed that takes into account acoustic backscatter enhanced by coherence in the particles’ spatial distribution as a result of turbulence-induced sediment fluctuations. This is based on a theoretically-derived relationship (Merckelbach, 2005) which has been tested against field surveys to calibrate the ferry observations (Merckelbach and Ridderinkhof, 2005). The calibrated data has identified that the greatest fluxes of sediment occur in spring and early summer. This suggests that biological processes may influence the magnitude of this net flux.

5.5 Use of FerryBox data to improve numerical models

The impact of assimilating FerryBox sea surface temperature (SST) data into a 3-dimensional model of the Irish Sea is illustrated in Figure 25. This shows the forecast on 21 October 2004 for simulations assimilating SAF satellite SST (SAF_real) and SAF plus FerryBox (FB) SST (SAF_FB_real) respectively. Within the fixed time window, the positions at which data are available for assimilation in the preceding analysis step are shown in Figure 26. This shows a small amount of SAF data in the Northwest, and data along the Birkenhead to Belfast ferry route. Both SAF and FerryBox data were assimilated assuming a radius of influence of 25 km around every data point. As we can see from Figure 25, inclusion of the FerryBox data introduces structures that were not present in the simulation assimilating SAF SST data only. The temperature is raised up to 1°C in some areas in Liverpool Bay with fine scale, frontal structures revealed.

The results obtained with assimilated FerryBox observations show a significant decrease in the Root Mean Square error. The appearance of finer scale structures in SST not present in the results obtained by assimilating SAF data only can also be seen. This can be explained by the scarcity of SAF data in this region in periods of heavy cloud coverage. In those times, the *in situ*, high resolution and regular FerryBox data can provide precious information for the areas surrounding the track with high (anti-)correlation values. Even when many other observational data sets are available, the FerryBox SST is an important piece of information due to its high accuracy and high-resolution sampling. Finally, the FerryBox data provides unique information at sampling frequencies required by smaller scale process studies.

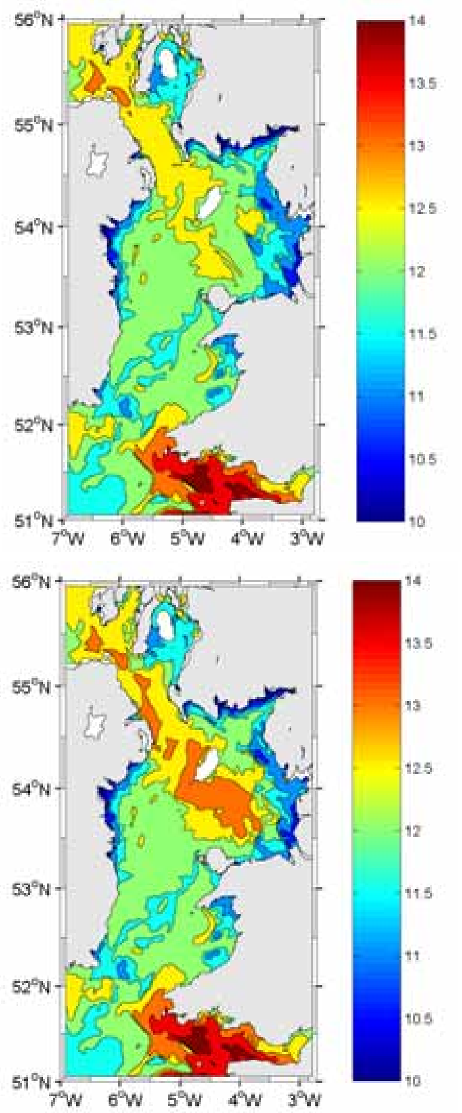

Figure 25 *Forecast for 21/10/04 for the simulations (upper panel) assimilating SAF data only and (lower panel) SAF and FB data.*

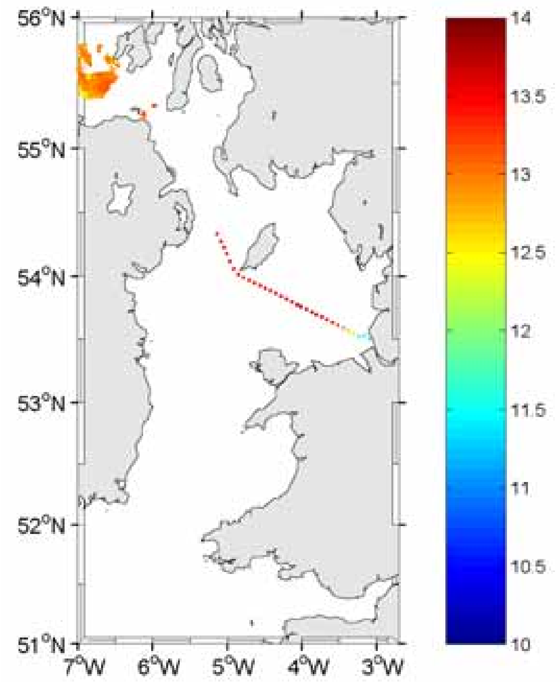

Figure 26 *Positions where data available for assimilation*

6 Costs of installed FerryBox systems: investment

6.1 Estimates of costs and effort

The costs for the procurement of instrumentation and the sensors as well as the installation costs are relatively low as in many cases standard components can be used (Table 3). Infrastructure which is already installed on the vessel (e.g. rooms, cable channels, water and energy supplies, communication equipment) can be used in support. The typical investment costs are in the range of 50000 EUR for a "standard arrangement" to 150000 Euro for a system with enhanced capabilities (such as integrated ADCP, automated sampler and/or algal group sensor).

Installation and set-up costs critically depend on the ferry and the desired level of operation and maintenance friendliness. Low-cost installations in or near the machinery room are achievable for around 10000 to 20000 EUR. More sophisticated installations, for instance with hull-mounted sensors or supported by a moon-pool, can usually only be made when a vessel is refitted or newly built. Such installations typically cost several 10000 EUR but may be supported by an interested ship owner (see below). The same applies for installations in the passenger areas which display data and associated information of interest which typically range from around 5000 to 10000 EUR (excluding specific programming and multi-media developments).

Operational costs of FerryBox systems need to cover the following activities:

- Servicing and maintenance
- calibration and referencing
- system operation and control
- data quality control
- pre- and post-processing
- archiving up to a stage "ready to use for applications".

The main cost factor is personnel. Across the FerryBox project this was experienced to be around 3–4 person months/year (inclusive of scientist, technicians and support staff) per operational system. An optimisation potential exists when an institution routinely operates more than one FerryBox system. Our limited experience of operating multiple systems suggests an increase by a factor of 0.5 for each additional system above that for the first system. Associated are costs for consumables, travels and communication which are very much application-dependant and summed up to an average of 5000–10000 EUR per year. For each measuring system the replacement costs for the FerryBox system ought to be taken into account in this cost category. Considering a typical life-time for marine monitoring equipment of 5 years and the aforementioned investment costs for a FerryBox system a budget of 10000–30000 EUR per year should therefore be considered.

Table 3 *Estimation of costs of a FerryBox system*

FerryBox Basic System (EUR)		
Standard FerryBox	37000–67000	Includes remote control and data storage computer, GPS system, basic sensor set (temperature, salinity, turbidity, Chl-*a* fluorescence), Software[a]
Shore-based station	6500	Database and presentation system on PC
Installation onboard (pumps, tubes, plumbing etc.)	4000–12000	Depends on ship and configuration of the FerryBox (standard or enhanced)
Additional Sensors/Analysers (appr. EUR)		
Oxygen-Optode® & pH	4000	
UV nitrate Detector	15000	UV detection (only for nitrate)
Filtration unit	1500	For wet chemical analysis of nutrients
Nutrients (single channel)	22000	Wet chemical analysers
Nutrients (double channel)	25000	
Algal groups	19000	Excitation at different wavelengths
ADCP	36000	
pCO2 Measuring System	60000–70000	
Operation Cost (EUR per year)		
Consumables and spare parts	3000–12000	
Communication fees	600–2400	Depending on data volume
Reference analysis (water samples)	500–4000	Laboratory analysis of salinity, chlorophyll and nutrients
Maintenance of sensors (CTD, fluorescence)	1000–2000	Yearly check and recalibration by the manufacturer
Operation Cost (person months per year)		
Operation, maintenance and supervision (basic system)	3–6	Standard system
Additional sensors (e.g. nutrients)	3–10	Depending on system complexity

[a] For one system (4H Jena, Germany) an automatic antifouling unit is included

With regard to investments, installation and operation costs one should keep in mind that all systems applied in the project were either institution-designed prototypes or small pilot-series or prototypes. With increasing applications and further transfer of results, experiences and technologies into the marine industry community it is expected that FerryBox systems will become more standardised as well as easier to install, calibrate, maintain and operate. Overall this should lead to cheaper system costs and diminished efforts for their operation.

7 Advantages and limitations of FerryBox systems

FerryBox systems are a highly cost-effective monitoring tool. They produce a high yield of reliable high-frequency water quality data along a transect, improving conventional monitoring strategies. Many technical problems typical for stand-alone marine measuring systems are not a problem for Ferryboxes. These include constraints in availability of electricity, installation and storage space, protection of components against harsh marine environments and longer-term fouling. As the measuring device always “comes back to the operator”, servicing and calibration can be done directly in port. Compared to offshore deployed devices the operation costs of FerryBox systems are significantly lowered.

However, even automatic systems need periodic maintenance and well-defined quality assurance to produce data sets of high quality. Oceanographic parameters such as water temperature, salinity and turbidity can be easily observed. For investigations on water and sediment transport an ADCP proved to be a very valuable and long-term stable instrument with low maintenance requirements. The applicability of oxygen and pH sensors as well as nutrient analysers has been shown. These data extend the information on biological processes although for nutrient analysers the effort for maintenance notably increases. For investigations of algal characteristics the available devices have to be further developed in order to be useful for routine analysis.

The yield on reliable data is high due to low-maintenance inline sensors and easy access for servicing at the home port. The high resolution of FerryBox systems in space and time provides deeper insights into marine processes which can be used to better assess the ecosystem and the underlying physical-biogeochemical processes in the marine environment. Special events like intense short-term algal blooms, rarely detected by standard monitoring methods, can be studied in detail and related to variations in influencing factors such as temperature, wind and nutrient load. This information can be used for further development of ecosystem models.

Techniques to assimilate FerryBox data into numerical models may be used to improve reliable forecasts. By combining remote sensing imagery with hydrodynamic model transports the ‘one-dimensional’ view along a ferry transect can be expanded into a 2D spatial view.

FerryBox systems do have limitations. Shipping lines are not always ideally positioned for the desired objective and thus a FerryBox application is often a compromise between available routes and scientific or monitoring needs. The installation possibilities depend on the goodwill of the vessel operator or owner. The systems have to be designed and operated in such a way that their installation and operation does not disturb the routine works and desired operation of the vessel. Also FerryBox systems must not interfere with other equipment installed on the ship nor require significant intervention (more than a few minutes per day) by the crew. The measuring depth of “standard” FerryBox systems is mostly limited to the mixed surface layer (depth 0–5 m) although it is possible to acquire some parameters with a wider depth range using advanced systems such as the ADCP.

For longer-term assessment and monitoring purposes the selected shipping route needs to be durably served. Vessel operators may from time to time terminate services, alter shipping routes, or replace a vessel at short notice. Also ferries can be quickly sold or companies may close down or change ownership. To cope with this a good relationship with the vessel’s operator is required to maintain operations. The “FerryBox” itself must be designed to be easily moved from one ship to another. The related experience of the CPR (Continuous Plankton Recorder) surveys operated by SAHFOS (www.sahfos.org) shows however that effective monitoring can be maintained in the long term.

Compared with other marine monitoring and measuring systems Ferryboxes acquire very large amounts of data. Hence quality control, evaluation and processing need to be highly automated, robust and reliable. New procedures for data processing and evaluation therefore have to be developed especially when Ferryboxes are used routinely and in increasing numbers in operational services. However, considerable progress was made by the FerryBox project towards developing the necessary procedures.

8 Recommendations

Automated systems on ferries or ships of opportunity will play a major role in the near future for ocean and shelf sea observations. The importance of FerryBoxes on ferries and ships of opportunity has been outlined by organisations such as EuroGOOS, and will be important in the context of the European Water Framework Directive and European Marine Strategy.

In this context, the monitoring and understanding of coastal and shelf seas, with their large spatial heterogeneities and temporal variability, will gain very much from these systems.

Authorities, agencies or scientific institutions that consider a potential future implementation of a ferry system in their research/monitoring should consider the following recommendations:

- In the planning phase a careful assessment should be carried out to judge whether the ferry/ship route meets the objectives of the monitoring or research tasks. For example, will surface measurements from a ship yield enough information to reach the objective or should a combination with buoys be considered?
- In order to choose the appropriate FerryBox system for the planned task, helpful hints can be obtained in the deliverables D-2-1 “Report on the functionality of FerryBox systems” and D-2-3 “Interim report on the experiences with the FerryBox during operational use” (available from www.ferrybox.com).
- The type of instrumentation, i.e. sensors or analysers, their applicability and their limitations for the intended task and the meaningfulness of the scientific results obtained with these instruments should be assessed in advance.
- The effort/expenditure of the maintenance that depends on the number and type of measured parameters should be carefully considered.
- Even when a FerryBox system is highly automated, the potential user should keep in mind that regular (1–2 days) data checks and regular maintenance/calibrations (weekly to bi-monthly, depending on instrumentation and required accuracy) are needed.

9 Outlook and future developments

The future requirements of marine environmental monitoring and operational oceanography as demanded not only by GOOS and its regional implementation initiatives, but also by several policies such as the European Water Framework Directive (WFD), include increased capacities, improvements and enhancements of spatial and temporal coverage. FerryBox systems can act as a supplementary component for relatively low costs or even without cost increase.

During the GOOS Scientific Steering Committee (GSSC) meeting in Paris (6–8 March 2006) the FerryBox concept was adopted as a Pilot project for the Coastal Implementation of GOOS. This will give additional recognition to the FerryBox concept on a global scale.

After finishing the EU FerryBox project at the end of 2005, most of the activities which were started in the project have continued. New installations of FerryBoxes by water authorities (RIKZ in The Netherlands), or in Norway by institutes like NIVA with two more lines, have taken place or are in the strategic planning phase. In Germany, BSH has plans for the Baltic and the North Sea. Further activities in the North Sea are underway for the North West Shelf supported by NOOS and for an integrated Marine Ecosystem Observatory (EMECO) (Mills *et al.*, 2006). The FerryBox systems currently running play an important role in the EU Framework 6 project ECOOP for delivering *in situ* data for the modelling activities.

Early warning of Harmful Algal Bloom events enables action-specific contingency plans to be put in to mitigate damage to human health and economic losses. For these tasks, automated systems on ferries and ships of opportunity can supplement operational monitoring methods, e.g. from buoys.

Other FerryBox-type activities are underway in the United States: the FerryMon project in North Carolina, (Ensign and Paerl, 2006), in Nantucket Sound (sealion.whoi.edu/ferries/), in the Georgia Strait (www.stratogem.ubc.ca) and even onboard a cruise liner in the Caribbean Sea (www.rsmas.miami.edu/rccl/).

10 Acknowledgement

This work was supported by the European Commission under the 5th RTD Framework Programme, Contract no. EVK2-CT-2002-00144. We would like to thank all involved ferry companies and the crews onboard the ferries for their support.

Table 4 *Ferry companies involved*

Route	Company	Ship	Address	Web site
Helsinki (FI) –Travemünde (DE)	Finnlines OY	Finnpartner	P.O. Box 197 FIN-00181 Helsinki Finland	www.finnlines.fi
Helsinki (FI) –Tallinn (EE)	AS Tallink Grupp	Romantica	Tartu mnt. 13 10145 Tallinn Estonia	www.tallinksilja.com
Oslo –Frederikshavn	Color Line	MS Color Festival	Postboks 1422 Vika NO-0115 Oslo Norway	www.colorline.no
Cuxhaven (DE) –Harwich (UK)	DFDS A/S	Duchess of Scandinavia	Sundkrogsgade 11 DK-2100 Copenhagen Denmark	www.dfdsseaways.dk
Den Helder –Texel	TESO (Texels Eigen Stoomboot Onderneming)	Dr. Wagemaker	Pontweg 1 NL-1797 SN Den Hoorn The Netherlands	www.teso.nl
Birkenhead (UK) –Belfast (N-IRL)	Norse Merchant, now Norfolkline	Lagan Viking	12 Quays Terminal Tower Road Birkenhead Wirral CH41 1FE United Kingdom	www.norfolkline.com
Southampton (UK) –Cowes	Red Funnel Travel Centre	Red Falcon	12 Bugle Street Southampton SO14 2JY United Kingdom	www.redfunnel.co.uk
Portsmouth (UK) –Bilbao (ES)	P&O Ferries Limited	Pride of Bilbao	Channel House Channel View Road Dover CT17 9TJ United Kingdom	www.poferries.com
Athens –Heraklion	Anek Lines	KRHTH II	Karamanlis Avenue Chania, Crete Greece	www.anek.gr

***Table 5** Project partners involved*

Project partners		
GKSS Research Centre (coordinator) Institute for Coastal Research	GKSS	www.gkss.de
Natural Environment Research Council George Deacon Division for Ocean Processes Southampton Oceanography Centre (now National Oceanography Centre, Southampton)	NERC.NOC	www.noc.soton.ac.uk
Royal Netherlands Institute of Sea Research Department of Physical Oceanography	NIOZ	www.nioz.nl
Finnish Institute of Marine Research	FIMR	www.fimr.fi/en.html
Hellenic Centre for Marine Research	HCMR	www.hcmr.gr
Proudman Oceanographic Laboratory	NERC.POL	www.pol.ac.uk
Norwegian Institute for Water Research	NIVA	www.niva.no
HYDROMOD Scientific Consulting	HYDROMOD	www.hydromod.de
Chelsea Technologies Group	CTG	www.chelsea.co.uk
Spanish Institute of Oceanography	IEO	www.ieo.es
Estonian Marine Institute	EMI	www.sea.ee

11 Glossary

ADCP	Acoustic Doppler Current Profiler
AOA	Algae Online Analyser
BODC	British Oceanographic Data Centre
BSH	Bundesamt für Seeschifffahrt und Hydrographie
ECOOP	European COastal-shelf sea OPerational observing and forecasting system
EU	European Union
EuroGOOS	European component of GOOS
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HPLC	High Performance Liquid Chromatography
NOOS	Northwest European Shelf Operational Oceanographic Services
REVAMP	Regional Validation of MERIS Chlorophyll products in North Sea Coastal Waters
RIKZ	Rijksinstituut voor Kust en Zee
SAF	Satellite Application Facility
SAHFOS	Sir Alistair Hardy Foundation for Ocean Science
SOO	Ships Of Opportunity
UNESCO	United Nations Educational, Scientific and Cultural Organization

12 References

Bargeron, C.P., D.J. Hydes, D.K. Woolf, B.A. Kelly-Gerreyn and M.A. Qurban, 2006. A regional analysis of new production on the Northwest European shelf using oxygen fluxes and a ship-of-opportunity. Estuarine Coastal and Shelf Science. 69, 478–490.

Ensign, S.H. and H.W. Paerl, 2006. Development of an unattended estuarine nutrient monitoring program using ferries as data-collection platforms. Limnology and Oceanography Methods 4, 70–76.

Fischer, J., J. Baretta, F. Colijn and N.C. Flemming (eds), 2000. Bio-ecological Observations. In Operational Oceanography. EuroGOOS Publication No. 15, Southampton Oceanography Centre, Southampton. ISBN 0-904175-43-X

Fischer, J. and N.C. Flemming, 1999. “Operational Oceanography: Data Requirements Survey”, Publication No. 12, Southampton Oceanography Centre, Southampton. ISBN 0-904175-36-7.

Fleming, V. and S. Kaitala, 2006. Phytoplankton spring bloom intensity index for the Baltic Sea estimated for the years 1992 to 2004. Hydrobiologia 554, pp. 57–65.

GOOS, 2005. An implementation strategy for the coastal module of the Global Ocean Observing System. GOOS Report No. 148; IOC Information Documents Series N°1217; UNESCO.

Joint, I. and 26 others, 2001. “Pelagic production at the Celtic Sea shelf break–the OMEX I project” Deep-Sea Research II 48(14/15): 3049–3081.

Kaitala, S., M. Raateoja, V. Fleming P. Maunula, S. Hällfors and E. Rantajärvi, 2004. 11 years of Alg@line and future perspectives. Presentation on the FerryBox Open Science Conference, 4–5 October 2004, Southampton Oceanography Centre, Southampton (UK).

Kelly-Gerreyn, B.A., D.J. Hydes, A.M. Jégou, P. Lazure, L.J. Fernand, I. Puillat and C. Garcia-Soto, 2006. Low salinity intrusions in the western English Channel. Continental Shelf Research 26, 1241–1257.

Lavín, A., L. Valdes, F. Sanchez, P. Abaunza, A. Forest, J. Boucher, P. Lazure and A.M. Jegou, in press, “The bay of Biscay: The encountering of ocean and shelf” Chapter 23a in the Sea.

Merckelbach, L.M., 2006. A model for high-frequency acoustic Doppler current profiler backscatter from suspended sediments in strong currents. Cont. Shelf Res. 26 1316–1335.

Merckelbach, L.M. and H. Ridderinkhof, 2006. Estimating suspended sediment concentration using backscatterance from an acoustic Doppler profiling current meter at a site with strong tidal currents. Ocean Dynamics 56, 153–168.

Mills, D.K., P. Walker, J.M. Rees, S. Malcolm, C.J. Fox, M. Edwards, R. Laane, P. Bot, H. Ridderinkhof, F. Colijn, W. Petersen, F. Schroeder, H. Wehde, J. Johannessen, E. Svendsen and B. Hackett, 2006. Development of a European Marine Ecosystem Observatory (EMECO). ICES CM 2006/E:10.

Najjar, R.G. and R.F. Keeling, 2000. Mean annual cycle of the air-sea oxygen flux: A global view. Global Biogeochemical Cycles 14, 573–584.

Petersen, W., F. Colijn, J. Elliot, M.J. Howarth, D.J. Hydes, S. Kaitala, H. Kontoyiannis, A. Lavín, I. Lips, K.D. Pfeiffer, R. Proctor, H. Ridderinkhof and K. Sørensen, 2006. European FerryBox Project: From Online Oceanographic Measurements to Environmental Information. In: Dahlin, H. *et al.* (eds) European Operational Oceanography: Present and Future. Proceedings of the 4th EuroGOOS Conference, Brest (France); ISBN 92-894-9722-2.

Petersen, W., H. Wehde, H. Krasemann, F. Colijn and F. Schroeder, 2006. FerryBox and MERIS–Assessment of Coastal and Shelf Sea Ecosystems by Combining *In situ* and Remote Sensed Data. accepted for Estuarine Coastal and Shelf Science.

Pingree, R.D. and D.K. Griffiths, 1978. Tidal fronts on the shelf seas around the British Isles Journal of Geophysical Research, 83, 4615–4622.

Rantajärvi, E., 2003. Alg@line in 2003: 10 Years of innovative plankton monitoring and research and operational information service in the Baltic Sea. Report Series of the Finnish institute of Marine Research, 48, 1−55 pp.

SAHFOS, 2004. Sir Alister Hardy Foundation for Ocean Science: Annual Report 2004. (Charity number 1001233), Citadel Hill, Plymouth, England. 40 pp.

Siegel, D.A., S.C. Doney and J.A. Yoder, 2002. The North Atlantic Spring Phytoplankton Bloom and Sverdrups Critical Depth Hypothesis. Science. 296, 730−733.

Wanninkhof, R and W.R. McGillis, 1999. A cubic relationship between air-sea CO2 exchange and wind speed. Geophysical Research Letters, 26, 1889−1892.

Wanninkhof, R., 1992. Relationship between Wind Speed and Gas Exchange over the Ocean. Journal of Geophysical Research, 97, 7373−7382.

WFD, 2000. Directive 2000/60/EC of the European Parliament and of the Council. Establishing a framework for Community action in the field of water policy. Official Journal of the European Communities L 327/1.

13 Contributors

Colijn, F., GKSS Research Centre, Geesthacht, Germany

Hydes, D.J., NOC, Southampton, United Kingdom

Kaitala, S., FIMR, Helsinki, Finland

Lips, I., Tallinn University of Technology, Tallinn, Estonia

Petersen, W., GKSS Research Centre, Geesthacht, Germany

Pfeiffer, K., HYDROMOD, Wedel, Germany

Proctor, R., POL, Liverpool, United Kingdom

Ridderinkhof, H., NIOZ, Texel, Netherlands

Schroeder, F., GKSS Research Centre, Geesthacht, Germany

Sørensen, K., NIVA, Oslo, Norway

Wehde, H., GKSS Research Centre, Geesthacht, Germany (now NIVA, Bergen, Norway)