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FerryBox

From On-line Oceanographic Observations to Environmental Information

Final Report

Detailed Report (Section 6)

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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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6.1 Background

Since several decades ships-of-opportunity such as ferries have been used to collect hydrographical data in coastal and oceanic waters. In the 1930-ties the Norwegians started to use the Hurtigruten, a ferry line running from Bergen all along the Norwegian coast up to Kirkenes, to collect salinity and temperature data on a regular basis. Also in the mid thirties Alistair Hardy in the UK 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). Nowadays these observations are still continued and build the longest biological records in the North Sea and northern Atlantic Ocean (SAHFOS, Annual report 2004).

Background of the EU application of the FerryBox project was several developments over the last decade. In the Baltic Sea the Finnish Institute for Marine Research started regular observations within a project called 'Alg@line' on the distribution of algal blooms and nutrient concentrations to be able to give of warnings on (toxic) algal blooms, mainly of cyanobacteria in the Finnish Gulf and the Baltic proper (Rantajärvi, 2003). Another goal of the frequent measurements was to detect long term changes in the eutrophication status of the Baltic Sea, which were reported in the environmental assessments for the Helsinki Commission (HELCOM).

Reports by the EUROGOOS organisation (EUROGOOS, 1999; Fischer et al., 2000) had shown that the possibilities to use ferries as ships-of-opportunity in Europe were manifold, due to the existence of over 800 regular ferry lines in European coastal and shelf waters and that several sensors to measure relevant physical, chemical and biological parameters were available.

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

Another argument which emphasizes the use of marine observations is the global change aspect. As shown by the results of the CPR long term changes of environmental conditions may also affect ecosystem properties. Global warming of the oceanic surface layers in the Northern Atlantic already gives rise to gradual changes in the zooplankton composition and distribution. This will eventually also lead to long term changes in the distribution of major (commercial) fish stocks in the Atlantic.

On a smaller scale data of the CPR have been used to entangle effects of nutrient inputs (eutrophication) and climatological forcing such as NAO on phytoplankton biomass and its distribution in the North Sea (figure from latest CPR Annual report). Such problems are covered by the activities under the Oslo and Paris Commission (OSPAR).

Thus a clear need to improve our observational capacities, not only on standard physical parameters such as temperature and salinity, but also on chemical (nutrients) and biological (phytoplankton, zooplankton) parameters is stated. This would help detection of trends in coastal and shelf seas of ecosystem parameters, could be used as data 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 detected along ship transects. Thus both spatial and temporal scales of marine processes could be much better resolved and understood.

A long term study which also covers most of these objectives is the Helgoland Roads series which started in the early sixties and has a high sampling frequency (several times a week) for a series of parameters such as phytoplankton composition, nutrients, turbidity, temperature and salinity. Also zooplankton observations have been made regularly. Recent analyses of these series were published by Wiltshire and Manley (2004) and Wiltshire and Dürselen (2004).

The work done by the Finnish colleagues over the last decade (Rantajärvi, 2003) offered a good basis for further developments of automatic measuring systems on board of ferries. Also in the meantime cost efficient new sensors became available which could be tested to broaden the range of observations especially in the field of biological oceanography.

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, up to shelf and coastal seas like the North Sea and the Bay of Biscay and the Mediterranean could be covered. This would enable the project partners to compare different water types under different climatological regimes within the project.

The cooperation with companies enabled further technological developments as well as an improved dissemination of the results.

The work performed within this project has been stimulated through discussions with the (Euro)GOOS community. Therefore within this global and European context the FerryBox project has achieved high visibility, which is reflected by the large number of presentations given during symposia and meetings.

In this project we will emphasize relations between the need for higher spatial and temporal coverage as needed for the EU Water Framework Directive (WFD) and the potentials to improve general objectives for water quality monitoring purposes. If higher demands are set for higher frequencies of measurements and spatial coverage the costs aspect gets more important. Reliable and cost effective observation methods therefore are a clear goal of this project.

6.2 Scientific/Technological and Socio-economic Objectives

Starting with the already existing and operational basic Finnish FerryBox and developments in a national project at GKSS, the partners actually aiming to operate their own system on board of a ferry line could make a quick setup based on available technology and commercially available sensors.

The technological objectives of this project were to further develop new measuring devices, to test newly developed sensors, and test the reliability of flow through systems on board of altogether nine ferry lines all over Europe.

At the start of the project sensors for salinity, temperature, turbidity, and fluorescence were commercially available. Also some nutrient sensors in the form of chemical analysers, as well as a newly developed nitrate sensor based on UV spectra were available. pH, oxygen and pressure and current sensors to control the performance of the measuring system were also available.

Further technological objectives were to compare these different sensors, manufactured by different companies and to try to inter-calibrate these sensors in such a way that reliable comparisons between the data become possible.

In a few cases other automatic equipment was tested such as an ADCP (Acoustic Doppler Current Profiler) to measure current velocities as well sediment loads, and tests were made with fluorescence based spectral instrument to resolve algal pigments. Also tests with a flow-cytometer were conducted.

The scientific objectives of this project were manifold: primarily differences between European coastal and shelf waters should be characterized on the basis of the parameters measured of which fluorescence, turbidity, temperature and salinity were mandatory. Seasonal differences and differences based on nutrient status were expected. These objectives have been used with respect to a series of scientific questions related to the discrimination of water masses and water transport, the transport of sediments through a tidal inlet, and the effects of eutrophication on different types of water bodies.

Secondary scientific objectives were strongly linked to the application of FerryBox data : can the FerryBox data be used for data- assimilation in (ecosystem) models, how can FerryBox data be used for remote sensing of the sea surface, or in the opposite way, can FerryBox data be used to validate remote sensing observations?

These scientific objectives and issues were treated in separate work-packages.

- Is eutrophication including plankton productivity and variability in productivity related to physical and bio-geochemical constraints
- How does transport of sediments (and associated contaminants) over long and short spatial and temporal scales take place
- Can we determine the transport of water masses in the Mediterranean, and Baltic Seas and on and adjacent to the Western European shelf with the help of FerryBox data
- How can we incorporate FerryBox data with data-assimilation into (ecological) models
- Can FerryBox data be used for validation of remote sensing observations

Thus we aimed to demonstrate the validity of the hypothesis that the FerryBox system can:

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

To reach these objectives the following activities have been carried out:

- Inter-calibration and comparison of available FerryBox systems, which run on 9 ferries.
- Collection of data from the above mentioned systems for a period of two years to prove the applicability, reliability and operability of such systems in different European waters.
- Improvement of the data availability for end-users by modern dissemination techniques and production of quality controlled and inter-comparable data sets.
- Derivation of relevant information required for monitoring, assessment and scientific understanding by data analysis and modelling.
- Provision of the end-user community with 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 REVAMP project.
- Offer possibilities to detect environmental impacts on large scales.

All chosen FerryBox routes have end-users who used of the products of the FerryBox project.

Socio-economic objectives in this project were diverse: through the activities of small companies impulses were expected towards technological improvements; the development of efficient new monitoring methods would deliver benefits for environmental agencies, whereas access to new scientific information might also help to improve operational models of hydrographical and meteorological services, thus being a contribution to GMES and GOOS. These improved and more cost efficient monitoring methods would help to establish new procedures and support existing ones for the EU Water Framework Directive. International agreements on environmental problems might also profit from new insights obtained through this project. Contributions might be expected to recent developments within the Coastal module of GOOS (UNESCO, 2005), for GMES, and other international monitoring projects.

6.3 Applied Methodology, Scientific Achievements and Main Deliverables

To achieve the scientific and technological objectives the project was set up according to 6 work-packages, covering the following aspects: WP-1: Project management and co-ordination, WP-2: Operation and metrology of the FerryBox Systems, WP-3: Management of the FerryBox data, WP-4: Scientific application of FerryBox data in specific applications, WP-5: Operational application of FerryBox data, and WP-6: Dissemination and Exploitation of results.

6.3.1 WP-1 – Project Management and Coordination

The project management and co-ordination was performed by the co-ordinator with help of the EU office, including the financial service department at the GKSS. Direct support for the project management was obtained from colleagues at GKSS participating in the project. A steering group consisting of the co-ordinator with the WP-leaders formed the basic management group of the project. The WP-leaders were responsible for the respective deliverables of their work packages.

Under the guidance of the project co-ordinator a group of main users was defined (representatives of environmental agencies as well as the EuroGOOS community), which acted as a Policy Advisory Board. During a few meetings this group was informed about progress of the project, and ideas and suggestions of this group were incorporated into the project. Reference to these meetings with the PAB can be obtained from the meeting summary report (Deliverable D-1-5). Occasionally bilateral discussions were organised at meetings where these representatives were attending (ICES Annual Science Symposium, EuroGOOS Meetings, ICES-IOC Steering Group meetings, GOOS Scientific committee e.g. in Cape Town (2003), Brest (2004), Melbourne (2005)).

Annual meetings were organized by partners in the project: 1st start up meeting at GKSS in 2003, 1st annual meeting at HCMR in Athens (Greece), 2nd annual meeting at NOC, Southampton (UK), and the 3rd annual meeting at the FIMR in Helsinki (Finland). In between meetings were organized for smaller groups within the project to discuss current issues and make arrangements (NIOZ, Texel, in February 2004). In February 2005 an intermediate meeting was held at the Spanish Institute for Oceanography (IEO) in Santander.

6.3.2 WP-2 – Operation and Metrology of the FerryBox Systems

6.3.2.1 Objectives

The objectives in WP-2 were to organize and to care for the operation of all FerryBox systems on the nine routes within the project. This implies

- Installation the FerryBox systems on all ferries which should be completed within the first year
- Continuous operation of the systems in the second and third year
- Developing standard schemes for validating the accuracy and precision of the obtained data (metrology)
- Delivering quality controlled data to WP-3 from the sensors of the core parameters (water temperature, salinity, turbidity and chlorophyll-a fluorescence)
- Running sensors for additional parameters (nutrients, ADCP etc.) for specific questions on certain lines

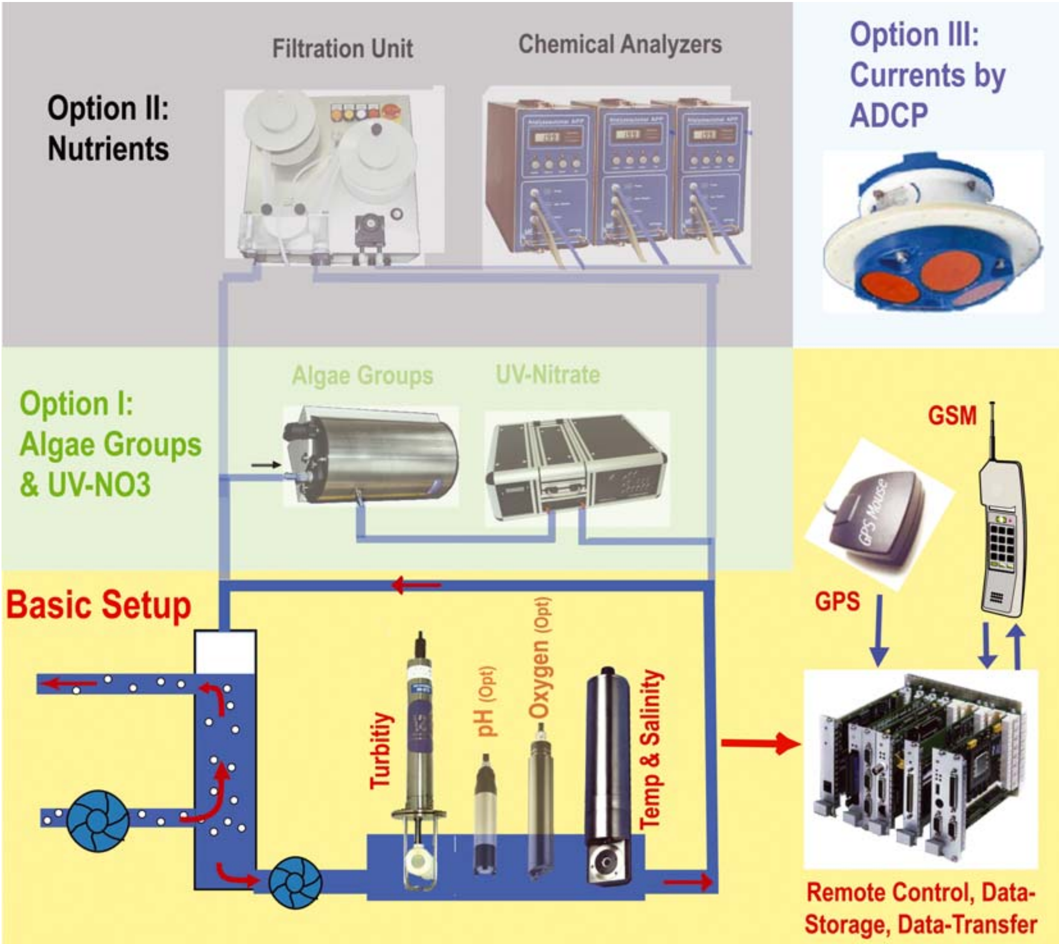


Figure 3-1: Principle design of a flow-through system of a FerryBox including available options.

6.3.2.2 Operation and Functionality of the FerryBox Systems

A FerryBox as defined in this project is basically a flow-through system with a water intake point at a given fixed depth, normally between 1 and 6 meters depth. Two possibilities were used: a separate water intake point or a tap from one of the internal water flows of the ferry. The principles of such a flow-through system are schematically shown in Figure 3-1.

At the start of the project systems were in place on ferries in the Baltic Sea between Helsinki and Travemünde and between Helsinki and Tallinn, the Skagerrak , between Hirtshals and Oslo, and in the North Sea between Hamburg (later on from Cuxhaven) to Harwich in the UK, and between Southampton and the Isle of Wight.

Figure 3-2: Map of Ferry routes used in the EU funded FerryBox project.

All FerryBox systems reached an operational status until January 2004. Serious problems with low yield of reliable data for the first FerryBox year (from November 2003 to October 2004) occurred only on both new installed Ferryboxes 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) which has been updated once more at the end of the project.

Table 3-1: Overview of FerryBox systems on European ferries.

Area	Route	Observed parameters	Frequency	Period of operation
Baltic Sea	Helsinki (FI) – Travemünde (D)	T, Sal, Chl-a-fluorescence, nutrients	daily	1998 - today year around
	Helsinki (FI) – Tallinn (EE)	T, Sal, Chl-a-Fluorescence, nutrients (weekly from water samples)	daily	1998- today year around except ice covered periods
Skagerrak	Oslo (N) – Hirtshals (DK)	T, Sal, Turb, Chl-a-fluorescence, nutrients (weekly from water samples), PAR (partly)	2 times daily	Aug 2001 – today year around
North Sea	Cuxhaven (D) – Harwich (UK)	T, Sal, Turb, Chl-a-fluorescence, DO, pH, algal groups, nutrients	6-7 times per week	Sep-2003 – Oct-2005[1] year around
Wadden Sea	Den Helder – Texel (NL)	T, Sal, Chl-a-fluorescence, water currents & sediment transport (ADCP)	28 times per day	1999 – Dec-2004 year around [2]
Irish Sea	Liverpool (UK) – Belfast (UK)	T, Sal, (Turb, Chl-a-fluorescence)	daily	Jan 2004 – today
Solent	Southampton - Isle of Wight (UK)	T, Sal, Turb, Chl-a-fluorescence	several times per day	Apr 1999 – Nov 2004[3] from spring to autumn
Atlantic, Bay of Biscay	Portsmouth (UK) – Bilbao (ES)	T, Sal, Chl-a-fluorescence	2 times per week (3 day journey)	Apr 2002 - today
Aegean Sea	Athens – Heraklion (GR)	T, Sal, Turb, Chl-a-fluorescence	daily	Nov 2003 – Nov 2004 [4]

6.3.2.3 Experiences of Long-term Operation of FerryBox Systems

Operation of the FerryBox System

Apart from installing systems on ferries the reliability, availability and functionality of these systems is an important issue. Although there were differences in the quality of the systems, in the second and third year of the project most of the systems were running more of less the year round with the four standard sensors with only short gaps and delivered reliable data over the whole time. Reasons for longer interruptions of the operation where docking times of the ferries (in the winter months), ice cover in the Baltic Sea. Only short (within weeks) breakdowns were encountered by broken instruments or failures in the FerryBox system.

[1] Ferry route out of service since November 2005
[2] Out of operation in 2005 due to delayed start of a new build ferry with a moon pool
[3] Out of operation since Nov 2004 due to lack of manpower
[4] Out of operation in 2004 due to shifting of the ferry-boat to another line

Figure 3-3 shows an example of the merits of the FerryBox system in the Skagerrak area. The figure clearly shows that this system had 90% availability during the period of operation.

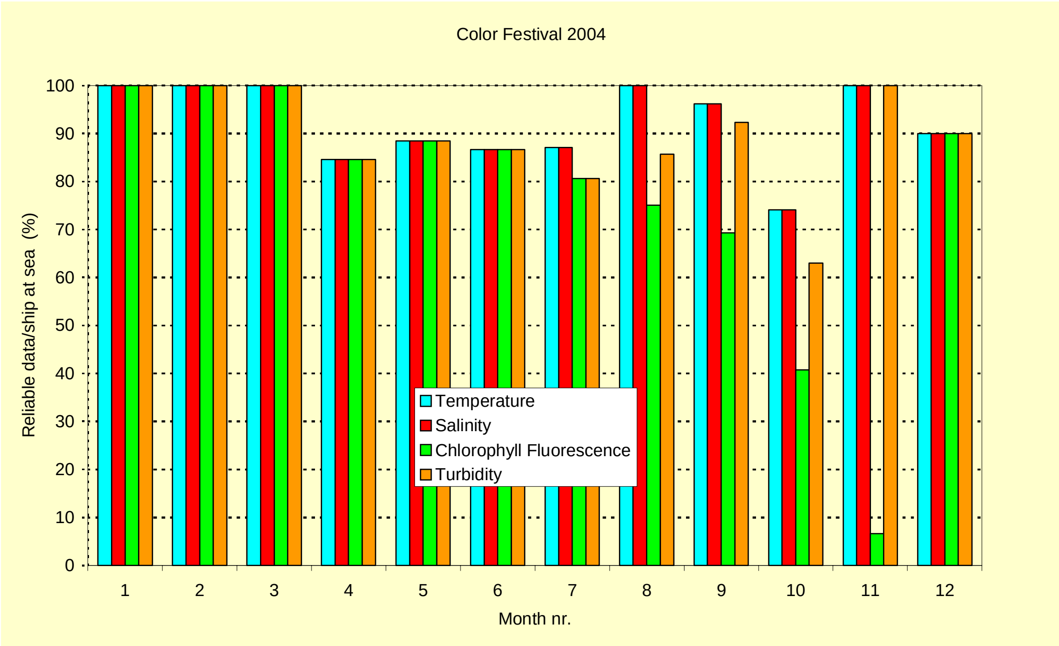


Figure 3-3: Availability of the core parameter in the Skagerrak in year 2004.

Serious problems occurred on the routes in the Irish Sea and the Mediterranean Sea due to lack of maintenance power or difficulties to access the ferry for an appreciable length of time. Even if the systems run more or less automatically it reveals that a long-term and reliable data set can only be achieved by regular check of the data and regular maintenance of the system.

Another problem that turned out was that on some routes the ferry companies changed their vessels or changed the route of the used ferry boat during the lifetime of the project. This led to longer interruptions in the Irish Sea and as well as in less extent on the route between Tallinn and Helsinki. In 2005 in the Mediterranean Sea and on the route to Texel the FerryBoxes were not in operation due to problems with the ship.

At the end of the project in October 2005 the operation of the ferry line between Germany and England (Southern North Sea) was finally stopped because this route was no longer profitable for the ferry company.

Standard Sensors

The so called standard parameters which should be measured on all nine FerryBox systems were water temperature, salinity, chlorophyll-a fluorescence and turbidity.

In general the sensors for temperature and salinity were operated without major problems in most cases. 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 about 0.5 – 1 °C were reported. In order to circumvent this, an additional temperature sensor as close as possible to the inlet or even on the ship hull is recommended.

The experiences with salinity sensors were different. Some devices run very 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 can already cause serious changes in the calibration factor.

Most of the systems run with manually cleaning of the system. Sometimes this led to problems with biofouling especially at the salinometer and even to a greater extent at the turbidity and fluorescence sensors. The biofouling problems only can be avoided by frequent cleaning of the system in particular at times of high biological activity. Only the systems on the German and on the Greek ferry were equipped with an automatic cleaning system (cleaning of the whole system with acidified tap water after each cruise) which efficiently prolongs the necessary maintenance intervals and the reliability of the data. Turbidity measurements were not carried out on all ferries. It turned out that the turbidity sensor is very sensitive against fouling but that a wiper on the windows of this sensor effectively reduces these problems. In some systems small air bubbles causing a background made it difficult to measure turbidity accurately at very low values.

At the end of the project reliable turbidity measurements were only available for the routes in the Skagerrak and in the North Sea. Direct chlorophyll-a fluorescence data are difficult to interpret due to the dependence of the fluorescence yield on the pre-illumination, species and physiology of the measured algae. Calibrations with measurements of extracted chlorophyll show that the fluorescence to chlorophyll rate varies up to one order of magnitude depending on location and time of the year.

In more detail the experiences on the different FerryBox systems were documented in deliverable D-2-3 (Report on the experiences with the FerryBox system).

Metrology of FerryBox Systems

One task in WP-2 was the development and application of effective calibration and quality control procedures (metrology). It is not self evident that running FerryBox systems automatically deliver good and sound data. Therefore a lot of energy had to be put into calibration procedures which partly had to be developed during the project. This issue has two elements: the data quality of one particular sensor or FerryBox system, as well as the comparison between the measuring systems on the different ferry lines. The latter proved to be a laborious task which could not be completely solved during the project.

The cause of this problem is inherently connected to the lack of standardisation of measuring equipment within Europe and beyond. For most parameters a whole suite of sensors are offered which all have different characteristics. This hinders an easy inter-calibration between the sensors because the measuring principles maybe different.

The data quality assurance measures particularly were already established on routes which operated since several years. On other routes quality control procedures had to be newly set up. The common metrology procedures were defined in deliverable D-2-2 (Report detailing the standard procedures on calibration and quality control procedures). The partners agreed to deliver their data about calibration and validation of the sensors on their FerryBox systems to CTG on a monthly basis in order to keep track on this activities. From several reasons this agreement was not kept from all partners. The metrology task partially suffered on insufficient acceptance of the partners to install appropriate metrology measures. Main reasons were the lack of sufficient and qualified man power.

The metrology data showed that data of high quality only can be obtained over a longer time period if the reliability of the data is checked on a regular basis and if the calibration of the instruments is periodically checked. This can be done either by water samples and subsequent analysis in the lab (e.g. for salinity, chlorophyll-a, turbidity and nutrients) or by onboard calibration during maintenance (e.g. oxygen, pH).

In the case of the standard sensors the main reasons for calibration shifts are not instabilities of the used sensor but drifts due to biofouling. A special problem is the conversion of fluorescence data to chlorophyll-values as described above. On some routes this relationship has been measured in water samples on a weekly basis in order to get reliable true chlorophyll-a values.

Two inter-comparison experiments have been carried out between the partners. In the first inter-comparison Formazin standards certified by NIVA were distributed to the partners for checking the different turbidity sensors in order to make the data more comparable. In a second experiment an inter-comparison of chlorophyll-a analysis in the lab conducted by NIVA with seven partner from the FerryBox project revealed that at low chlorophyll concentrations and algae species which are difficult to extract the standard deviation is still very high (up to 44%).

The problems with suitable and reliable metrology procedures revealed that it is not granted to deliver good and sound data even on such automated systems like the FerryBox. Although much effort has been put into calibration procedures and their operation, more needs to be done to be sure about the data quality.

Experiences with Non-standard Sensors

In addition to standard sensors other instruments for water currents and sediment transport as well as for nutrients, oxygen and pH have been tested on certain ferry lines. On the route between Den Helder and the island of Texel it could be shown that an ADCP (Acoustic Doppler Current Profiler) mounted under the keel of a ship is a very valuable 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 are very helpful. The new optode for oxygen measurement and even a standard Clark oxygen sensor seem to be very stable over long time periods in such flow-through systems. However, the used glass electrodes for pH still suffer from an insufficient accuracy.

Onboard the ferry in the Southern North Sea chemical nutrient analysers and in addition an in situ nitrate sensor (UV detection) has been tested as well. It turned out that wet-chemical analysers require a high effort on maintenance in order to get accurate data. The UV nitrate sensor needs lower maintenance although the higher detection limits makes this sensor less suitable for the open sea.

For a better characterisation of algae (species, productivity) a new device for algal group detection (AOA, bbe-moldaenke) as well a fast repetition rate fluorometer (FRRF, CTG) for in-situ measurements of photosynthetic characteristics of phytoplankton have been tested. The AOA only give semi-quantitative data of the algal groups however the data give good indications of changes in the algal species. The FRRF has been tested only for short period however the complexity of the data suggests that it should not be considered for routine analysis.

A very helpful tool is an automatic water sampler in order to get reference samples which can be analysed in the lab as well to study phytoplankton and other constituents in the lab in more detail.

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)

Conclusions

In conclusion it turns out that a FerryBox system is a cost-effective monitoring tool to get a high yield of reliable high frequent water quality data along a transect improving conventional monitoring strategies. The yield on reliable data is high due to low-maintenance inline sensors and easy access for services at the home port. The high resolution of FerryBox systems in space and time provides deeper insights in marine processes which can be used for better assessing the ecosystem and the underlying biogeochemical processes in the marine environment. Special events like strong short-term algae blooms, which will be detected only occasionally 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 combination with remote sensing images and together with hydrodynamic transport models the 'one-dimensional' view along a transect of the ferry even can be enlarged to a more spatial view.

However, even such automatic systems needs periodically maintenance and metrology procedures to produce data sets of high quality. Oceanographic parameter 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 effort on maintenance. The applicability of oxygen and pH sensors as well as of nutrients analysers has been shown. These data extend the information on biological processes although especially for nutrient analysers the effort for maintenance increases notably. For investigations of algal characteristics the available devices have to be further developed in order to use them for routine analysis.

6.3.3 WP-3 – Management of FerryBox Data

This work package encompassed the activities regarding management and handling of the large amount of data and information produced within the FerryBox project.

6.3.3.1 Project Data and Information Management

To harmonise and optimise data and information exchange among the project partners a Project Data and Information Management Plan ("FerryBox DIMP" – deliverable D-3.1) was established and implemented. This harmonises processing and exchange of data and information among the project partners for project internal purposes.

6.3.3.2 Common Format and Standards for FerryBox Data

One of the main goals was elaborating a common format, a joint data inventory and unified meta-data contents for effective data assembly and exchange which ought to be compliant with technology and affiliated guidelines and standards in Europe. The project partners agreed on a simple and easy to handle data format allowing effective data exchange as well as further use of the data acquired by the different FerryBox systems and operators. This format is also easy to use of the data by third parties as well as for import to and export to/from almost arbitrary user applications.

All data produced by the project reveal certain common standards such as being uniquely time and space referenced (e.g. UTC time, WGS-84 coordinates given in decimal degrees).

Each data value is controlled by an as far as achievable commonly agreed quality control procedure established in WP 2 [5] and accordingly marked with the standard BODC quality data flags.[6] Optionally each operator of a FerryBox system can apply different or own-defined quality flags in addition. This is especially useful if data are transferred to other data inventories and NODCs which may apply different and more extensive QC flagging than the BODC as well as to indicate different levels of quality control and/or post-processing.

Also optionally a so called "data reference flag" is included for the dependant (measured) parameter which can indicate whether a water sample was taken simultaneously with the automatically measured date. This is useful for cross-referencing to samples being precisely analysed in the laboratory and, more generally, for means of calibration and data quality checking.

Associated with the measured data a comprehensive and common data documentation (meta-data) was agreed which is in line with international requirements and standards. For parameter definitions this uses the BODC parameter dictionary. This is considered as important for future use of the data and also as a contribution European standardisation in marine and oceanographic data.

[5] In WP-2 the project partners agreed on a common set of maintenance and calibration procedures applicable for all types of Ferryboxes. An agreement on common quality control along with the data acquisition phases as well as for pre- and post-processing could not be achieved for reasons of considerable differences in application, data utilisation and related demands on data quality as well as due to regional differences and heterogeneity.

[6] The standard BODC quality flags indicate only 2 QC levels – good (by a BLANK flag) and doubtful data.

The unified set of meta data which associated to each data file includes information on

- The operating institution and responsible departments of the FerryBox system including contact persons.
- The ferry route and the platform (ferry) on which the system is
- The FerryBox system and measuring devices
- The associated data and parameters, their units plus information on the sensor, the data acquisition and quality control procedures.

The parameter dictionary comprising parameter classes, parameter names (partly associated to measurement procedures and/or devices) and standard units are a subset of the widely applied, recognised and constantly updated BODC Parameter Dictionary which facilitates European standardisation in this area.

More comprehensive information associated to a specific theme as well as external documents can be linked by URLs which are part of the meta-data.

Both the data and meta-data formats and contents are easily adaptable to almost all other types of time and geo-spatially referenced data.

For reasons of optimised data handling, different acquisition times of the sensors and instruments in the FerryBox as well as for subsequent data assembly, merging, export and import to other systems it was agreed that each data file includes only one dependent parameter (i.e. the one measured value), whereas the independent ones being date, time, latitude, longitude, measuring depth (below water level) and, where applicable, associated QC and reference flags appear for each data value. This has also the advantage that no data records appear which have partially empty records respectively missing values of the respective parameter. However, the common format and the associated meta-data allow also assembly of data records with practically infinite (limited by the record length only).

A comprehensive guideline document was elaborated and implemented therefore (deliverable D 3-2) which will become public after the end of the project. These guidelines may also stipulate other users for future applications in FerryBox data, and, even more generally, in oceanographic data production, documentation and quality control.

6.3.3.3 The Final FerryBox Data Collection

At the end of the project all operators of FerryBox systems assembled and documented their data for incorporation in a joint data inventory (the so called “Final FerryBox Data Collection”). For the final assembly and as final consistency control of the merged individually produced data sets some software has been developed by HYDROMOD.
The data collection will be published after the end of the project’s funded phase on a DVD together with a short documentation on its contents. The FerryBox data are freely available for interested users for scientific purposes. In addition the British Oceanographic Data Centre (BODC) acts as a data custodian. BODC will include these data into their data repositories and can also make them available through their data services.

6.3.3.4 Technical Work to Establish and Improve Data Access, Retrieval, Displays and FerryBox Websites

The work package incorporated also a series of individual activities conducted by the project partners for improving and optimising their individual data handling and management means for their FerryBox systems. Such comprised for instance functionality upgrading of user controls, on-line data retrieval and transmission to shore as well as improvements in automated pre- and post-processing. Also a variety of adaptations were done to produce or export the data from individual systems and applications in compliance with the project data management and assembly guidelines depicted above.

Further activities in this work package were dedicated to transferring and making the data available for various individual applications such as web-based services, online databases and websites. Also the related information technology developments of the FerryBox website, web pages and Internet data services were clustered under this work package (refer to the WP 6 on exploitation and dissemination for further details).

Within this work package also technologies for online data transfer and data availability/publishing in real- or quasi-real-time have been substantially developed further. Nowadays on several ferries on-line web access through ship-to-shore satellite communication links for control of the FerryBox systems and to displays status information and actual measurements is installed. A series of websites of the respective institutes enable on-line access to the FerryBox data and thereof derived data products (see WP 6 for details).

Database storage routines have been also developed as well as guidelines for the handling of FerryBox data. Furthermore the standardisation of the data handling, processing and retrieval systems considerably advanced throughout the project.

6.3.4 WP-4 – Scientific Analysis of FerryBox Data in Specific Applications

The key project objectives in WP-4 were to provide a scientific support for the principle that FerryBoxes can deliver information of immediate scientific value, based on a coordinated approach which can quantify environmental variability on a European scale. It concentrated on 3 scientific areas relevant to issues of water quality, eco-system stability and climate variability and change. (1) Eutrophication including plankton productivity and variability in productivity in relation to physical and biogeochemical constraints. (2) Transport of sediments (and associated contaminants) over long and short spatial and temporal scales. (3) Determination of the stability and transport of water masses. It implemented and tested the procedures and software developed in WP-2 and WP-3. The work was structured to provide a basis for the calibration and validation of the associated models developed in WP-5. In turn the data collected by the *FerryBoxes* was compared to data collected using research ships, remote sensing satellites and moored instruments on buoys. The observations presented in deliverable D-4-3, D-4-4, and D-4-5 are based on standardised reports which seek to systematically compare ecosystem and physical events in the Baltic, Skagerrak, North Sea, Irish Sea, English Channel, Bay of Biscay, Aegean Sea and the eastern Mediterranean.

Actions in WP covered all the majors areas of work planned for this work package - (1) Defining the different regions of water sampled by the FerryBoxes; (2) Using the FerryBox data to better understand the process controlling eutrophication and (3) sediment transport; (4) Comparing data from FerryBox to that collected by other systems.

6.3.4.1 Regional Hydrography

Identifying marine waters with different sources and properties

Representatives from all the partner institutions attended a meeting organised by NOCS and hosted by Royal NIOZ in February 2004 to develop a systematic basis for distinguishing the differences between the FerryBox routes and observations. These ideas were further discussed at the FerryBox Science Conference held at NOCS in October 2004. The procedure has now been applied to compare the data from the different routes for the two FerryBox years 2003 and 2004 where this data is available. It is proving to be an effective way of summarising the data as it enables the display of significant difference between the years such as the higher temperatures seen in the Bay of Biscay in 2003 and in the Gulf of Finland in 2004 and the shift in fresh water inputs in the Bay of Biscay between 2003 and 2004. This material is compiled in Deliverable D4.3-5 and Hydes et al (paper 2).

In the southern Bay of Biscay IEO (Gonzalez- Pola et al paper 4) have used the geographical coincidence of a FerryBox route in the south-eastern corner of the Bay of Biscay with a standard hydrographical section and satellite data. The different time series have been compared to analyse the capability of the systems to provide long-term high-resolution high-quality hydrographical time-series of the upper ocean. The inter-comparison exercise is based mainly in the Sea Surface Temperature (SST) as it is a well understood parameter dominated by a strong seasonal signal. The work demonstrates the ability of FerryBox systems to capture information on local short-scale features which may be lost with other sampling systems.

In the English Channel NOCS (Kelly-Gerreyn et al., paper 7) used the detailed time series from the FerryBox in conjunction with data for French river run off to identify 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 (Kelly Gerreyn et al., paper 9).

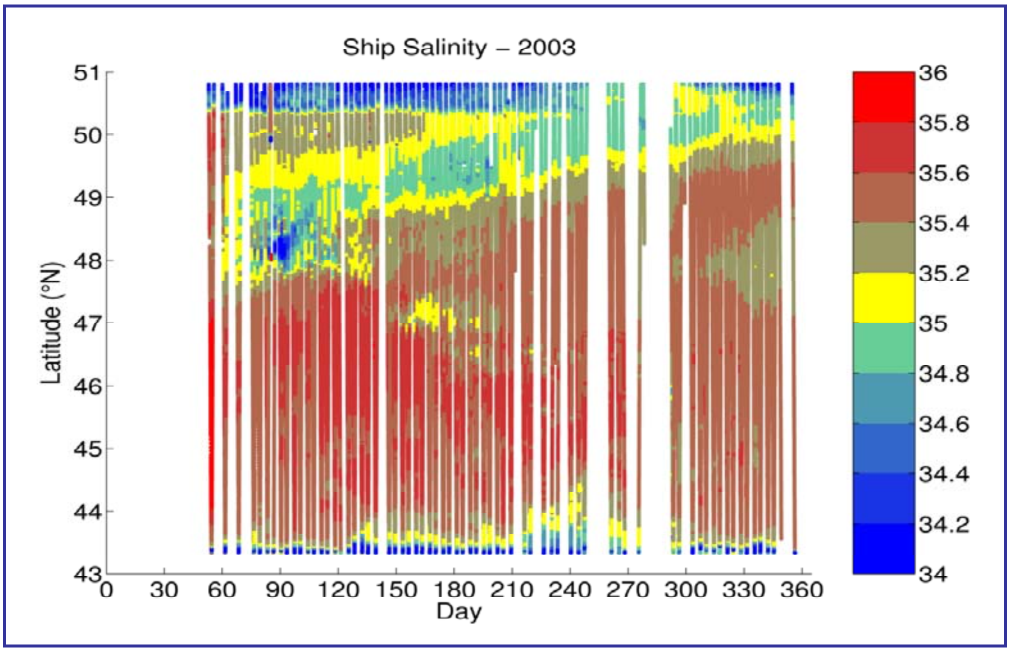


Figure 3-4: Sea surface salinity between Portsmouth and Bilbao in 2003 showing timing of the progress of low salinity waters into the western English Channel.

6.3.4.2 Eutrophication

A key contribution to this work is the development of a numerical indicator to summarise the data, which can be used by organisations such as the European Environment Agency as a management tool. This is based on work by FIMR (Fleming and Kaitala, 2005). The Fleming and Kaitala procedure has been tested by other FerryBox partners. A simple numerical index is calculated to describe the magnitude of the spring bloom in different regions and this is compared to the amounts of nutrient present at the end of winter (Hydes et al., paper 8). In general the expected general relationship between plankton biomass and nutrient load does exist. But data from the Baltic shows how widely the index and its relationship to concentrations of nutrients can vary from year to year. However up till now such clear relationships could not be observed in the compiled data set for the North Sea transect. Nevertheless, this provides a challenge, to extend the analysis to see if the reasons for these variations can be found in the available data sets. It also suggests that a degree of caution should be observed when trying to make judgements on the basis of data from a single year.

In the Bay of Biscay and English Channel it has been possible to link bloom activity to specific hydrographical features (Kelly-Gerreyn et al., paper 9). In the Baltic cyanobacterial blooms are a problem of specific interest.

EMI has analysed FerryBox data collected in years 1997 – 2004 to determine the main factors controlling the intensity and species composition of cyanobacterial blooms in the Gulf of Finland (Lips & Lips paper 11).

This has demonstrated that the difference between bloom and non-bloom years can explained predominantly by differences in amounts of photosynthetic active radiation and upwelling intensity. The changes in these two parameters can explain 46% of the variation in cyanobacterial bloom intensities.

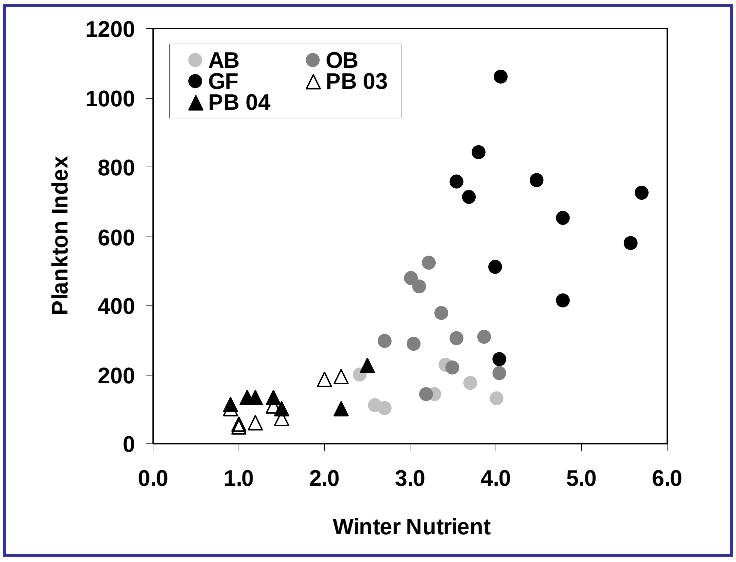


Figure 3-5: Plot of the spring phytoplankton bloom index against the geometric mean of the maximum winter nutrient concentrations – for results from the Baltic (Gulf of Finland - GF, Open Baltic -OB and Arkona Basin -AB) in 1992-2004 and Portsmouth to Bilbao in 2003 (PB 03) and 2004 (PB 04).

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., paper 10). This has allowed specific organism relationships to be determined.

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

6.3.4.3 Sediment Transport

All groups contributed to improving the consistency of measurements of amounts of suspended sediments through their contributions to the work in Work Package 2 lead by CTG and NIVA. This data is being used with other FerryBox data to contribute to the interpretation of satellite data. This includes work at NIVA, GKSS and IEO.

The main focus of the work of NIOZ has been on the use of FerryBox data in particular the application of ADCP (Acoustic Doppler Current Profiler) based methods to determine controls of sediment transport. The Texel to Den Helder ferry across the Marsdiep tidal inlet is equipped with a vessel-mounted ADCP. 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 each 30 minutes every day between 06.00 and 22.00 hrs) make the observations in principle suitable for such studies.

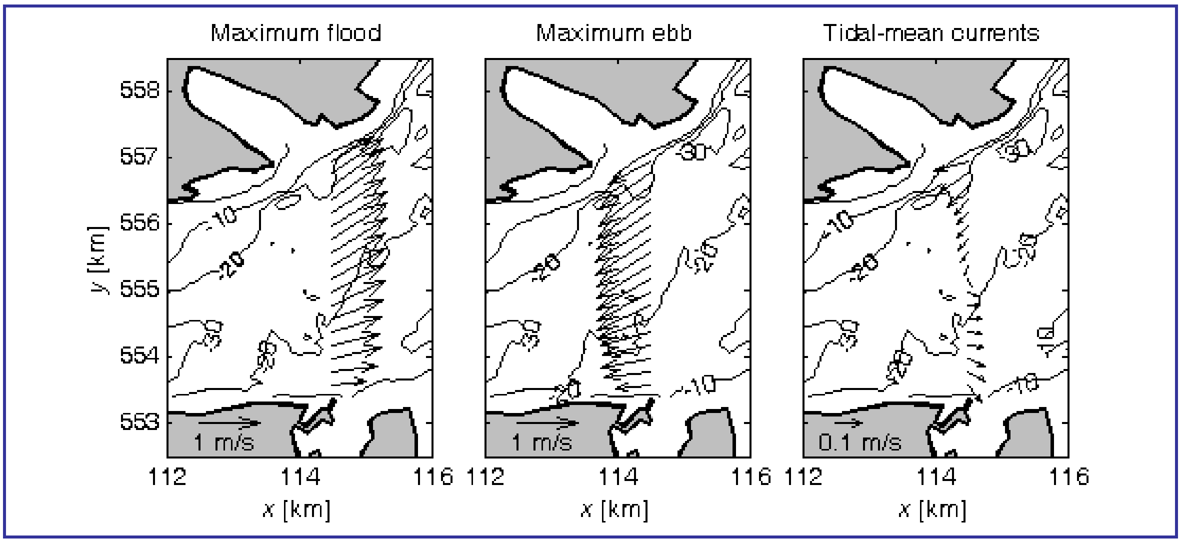


Figure 3-6: Typical examples of the depth-averaged tidal and mean currents in the Marsdiep inlet as observed with the ferry-ADCP on the route den Helder-Texel.

These studies found problems with the model commonly used to relate backscatter to suspended sediment concentration. A new model was developed that takes account of 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, paper 1a) which has been tested against field surveys to be used and calibrated against the ferry observations (Merckelbach & Ridderinkhof, 2005, paper 1b). 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 (Ridderinkhof & Merckelbach, paper 1c).

6.3.4.4 Comparison with other Systems

Data from buoys, satellites and research ships can be used in conjunction with FerryBox data. Combination of the FerryBox data with those from remote sensing and from research vessels allows in observations of the duration, and composition of blooms, to be extended to generate estimates for wider areas. Data extracted along the FerryBox tracks has been compared to data from the SeaWiFS, MERIS and MODIS and AVHRR satellite sensors. This work has been carried out by NIVA on data from GKSS, FIMR, NIVA, HCMR, NERC.NOC, NERC.POL, IEO & EMI.

For example limitations of the currently used algorithms for deriving chlorophyll-a from remote sensing images for coastal and shelf seas (Case-2 water) have been examined, as well as the problem of how representative sampling at a fixed depth or making surface observations are of the whole water column (e.g. Petersen et al., paper 15, Soto et al., paper 8 and Sørensen et al., paper 13).

In the Irish Sea and North Sea work has been carried out by POL and GKSS comparing FerryBox data generated by buoys and model observations. In the Irish Sea the ferry measurements are complemented by buoy measurements near the Mersey Bar and in Belfast Lough and by nested 3-D hydrodynamic and ecosystem models run daily, covering the ocean / shelf of northwest Europe (at 12 km resolution), northwest European shelf (at 7 km) and the Irish Sea (at 1.8 km). The ferry measurements have tested the temperature and salinity hindcasts of the Irish Sea model for 2004 and 2005 showing the importance of correct estimation of river discharge for the models.

In the North Sea a detailed examination was made (Wehde et al., paper 5) using a hydrodynamic model and an ecosystem model to compare the comparability of the FerryBox data and an adjacent data buoy (CEFAS Gabbard Buoy – Mills et al., 2003). This work has been valuable in demonstrating that the buoy and FerryBox data cannot be compared directly. The model demonstrates that the two sites are more distant from one another than might have been expected. However use of the model demonstrates that the two observational data sets are consistent with one another (Wehde et al., paper 5).

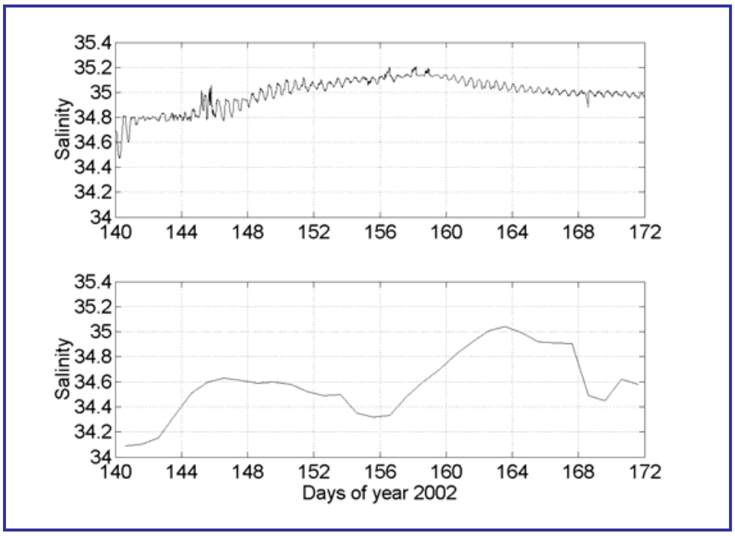


Figure 3-7: Comparison between Salinity data from Cefas Gabbard Buoy (upper panel) and FerryBox data (lower panel) using from the nearest geographical point of the route to Gabbard station.

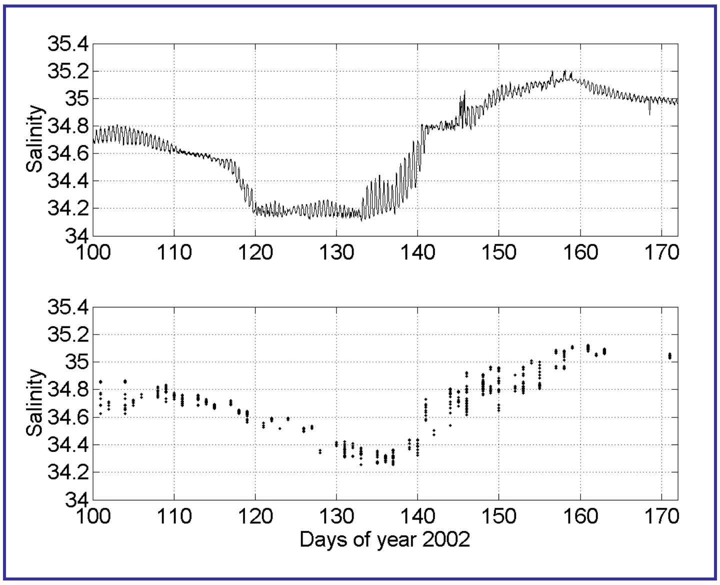


Figure 3-8: Comparison of salinity data measured at Cefas Gabbard Buoy (upper panel) with salinity data from passively tracers, observed with the FerryBox and transported within the GCM (lower panel).

6.3.5 WP-5 – Application of FerryBox Data

In this WP several tasks were fulfilled which centred on the topic: the use of FerryBox data in models to enhance our scientific understanding of underlying processes. The three scientific topics from WP 4, eutrophication, sediment concentration and transport, and stability and transport of water masses were treated and further analyzed in this WP. Additionally the use and value of FerryBox as collected on the different ferry lines were incorporated in existing models to see whether the models could be improved if data assimilation would take place. A final item which seems almost self evident is the use of FerryBox data to validate satellite observations. All these activities were covered by this WP-5, and are documented in a series of Deliverables (D-5-2, D-5-3, D-5-4) and publications (see annex to final report). Here a summary and several examples from these activities are presented.

6.3.5.1 Long Term Variability and Eutrophication

The analysis of eutrophication has been one of the items covered under WP4. Here modelling exercises directly linked to eutrophication processes are presented, by combining a physical ocean model with an existing ecological model.

Using the POL Coastal Ocean Modelling System (POLCOMS) coupled to the European Regional Seas Ecosystem Model (ERSEM), ecosystem variability during a 10 year period (1977-1986) in the Irish Sea has been investigated using a fine resolution (~3.5 km) local area model. The ability of the model to represent observed features of the nutrient cycling and plankton variability has been assessed by comparison with in-situ data and a long time series of measurements from a site to the southwest of the Isle of Man (Cypris station). Data extracted along the Birkenhead to Belfast ferry route indicate the route captures the significant elements of biochemical cycling in the Irish Sea.

Results from the Birkenhead – Belfast ferry in 2004 have been subject to an initial analysis. A temperature time vs. longitude plot (Figure 3-9) shows mainly the expected seasonal cycle with peak temperatures in August, but with some smaller features such as a heating event around day 160. Summer temperatures are higher in the shallower coastal water and in the stratified surface water at about 5 deg W. The NERC.POL Irish Sea model run for this period is in general agreement with this pattern except that model temperatures are approximately 0.5 – 1 ^{o}C higher. The salinity time vs. longitude plot (Figure 3-10) is possibly the more interesting as it shows distinct peaks of low salinity at the Liverpool end, corresponding to variations in the freshwater plume.

There is no obvious correlation with river outflow data, but a comparison with tidal data strongly suggests that the variations correspond to mixing at spring tides followed by restratification at neap tides. The variation in plume extent (several 10s of km) considerably exceeds the tidal excursion (total about 6 km due to M2 and 9 km at springs) which can also produce some variation in the apparent measured position of the plume. This stability cycle in Liverpool Bay has been observed by Sharples and Simpson (1995), but with a much shorter record. The NERC.POL Irish Sea model also shows similar oscillations in the extent of the plume and agrees with its general westward extent.

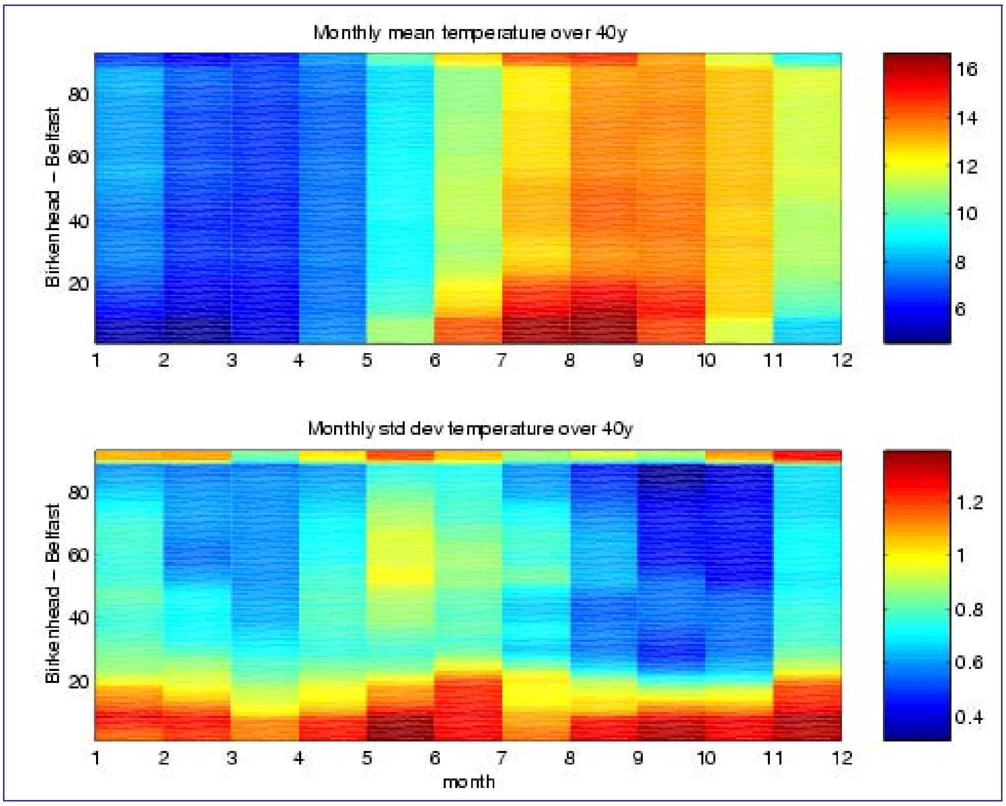


Figure 3-9: Temperature along the Irish Sea ferry route: 1960-1999. Y-axis: model grid-points.

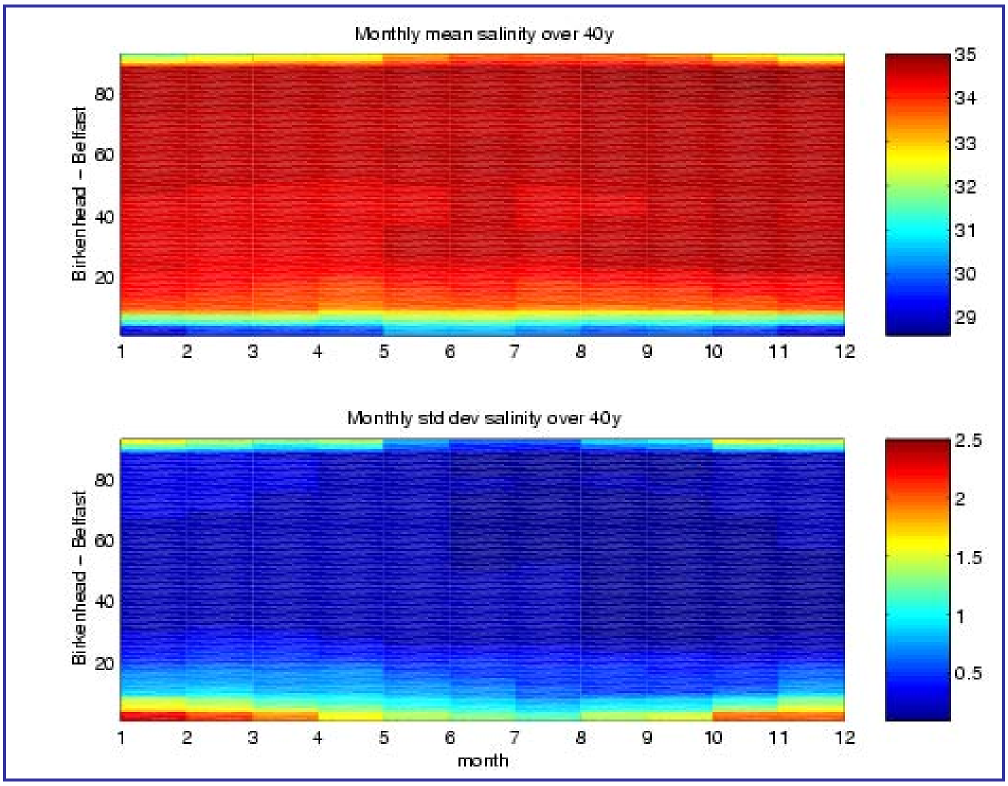


Figure 3-10: Salinity along the Irish Sea ferry route: 1960-1999. Y-axis: model grid-points.

However, the model was run with climatologically runoff only and this may affect the detailed comparison. A model run forced by the observed river runoff for 2004 (factored to allow for ungauged river discharge) shows modelled salinity in much better agreement.

Hence FerryBox data is potentially able to provide a long record giving information on the stability cycle in Liverpool Bay. Further comparison with models should help improve their ability to represent this important aspect of the dynamics of this region.

A detailed analysis of temperature and salinity data along the ferry track was made by extracting at daily intervals from the 40y run. These data were then averaged per month (i.e. all January tracks were collated) to produce a mean seasonal cycle and a monthly standard deviation. Figure 3-10show the mean and standard deviation for temperature and salinity respectively. Both indicate a mean seasonal cycle: in temperature this occurs predominantly across the whole track indicating the local effect of the seasonal heating and cooling cycle with some local enhancements close to both coasts; in salinity there appears no such cycle, however seasonal changes in salinity are seen close to both coasts with lower salinities in the winter than in summer. There appears no seasonal cycle in the standard deviation of temperature except in May, which correlates with the onset of stratification in the region west of the Isle of Man; maximum temperature standard deviation is 1.4C with strong along-route variability. Salinity standard deviation does have a seasonal cycle indicating that winter run off, especially in Liverpool Bay, can be variable; maximum salinity standard deviation is 2.5.

This shows the kind of variability we should expect to see in the FerryBox measurements in the Irish Sea and indicates the expected range of variability.

6.3.5.2 Water Mass Transport, Observed Changes and other Monitoring Data

As an example a model study carried out by GKSS shows the improvement of process understanding through modelling exercises concerning water mass transport, changes in observations and comparisons with other systems.

The role of advection was investigated by means of the example of the GKSS FerryBox operated on the route from Cuxhaven (Germany) to Harwich (United Kingdom). While running more or less the same track the spatial and temporal resolution of observations is very high along the route. However, the temporal and spatial information beside the ferry route is limited by definition. To improve the significance of the FerryBox data for the southern North Sea numerical models were applied to get deeper insight into the fate of water parcels measured by the FerryBox system. Consideration of tracer advection as well as primary production served as the explanation for deviations between FerryBox observations and data obtained by other methods.

Since FerryBox data sets are limited on the specific tracks of the ferries additional information aside the routes from e.g. fixed monitoring stations or remote sensing data are needed to resolve environmental characteristics with a broader spatial extension. However, the simple comparison between the FerryBox data and those from fixed stations by using the nearest geographical data points often fails, because of the predominant circulation pattern of the surrounding water masses and the lack of precise knowledge on the water transport times.

The models applied for the present study consist of a general circulation model (GCM), a Lagrangian Tracer model and a primary production module. The GCM uses an unstructured triangular grid and is forced with variable wind, tides and Coriolis force. A coupled nesting is applied for the estuary regions with highest resolution of the model in the southern German Bight and lowest resolution of the model in the northern North Sea (Plüß, 1999).

Water parcels measured with the German FerryBox were introduced as Lagrangian Tracers into the GCM in order to simulate the geographical displacement. To simulate the temporal development of non-conservative tracers like the chlorophyll a primary production module (Wehde et al., 2001) is implemented for each of the tracers.

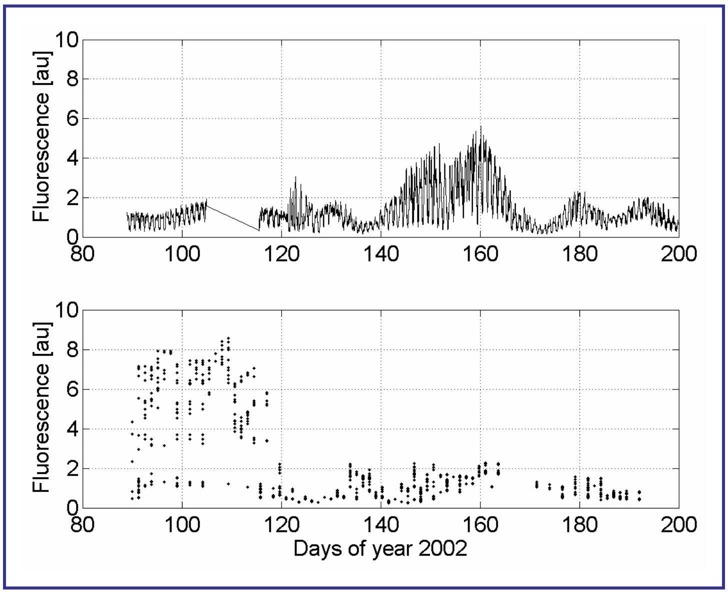


Figure 3-11: Chlorophyll fluorescence observed at Cefas Gabbard buoy (upper panel) and chlorophyll fluorescence of water passively transported within the GCM (lower panel).

The lack of reliable highly resolved biological data hampered the assimilation into numerical models in former times. The potential of the FerryBox systems combined with the mentioned model system improves the situation and large progress can be expected in marine ecosystem modelling. The results of the combination could either be used for validation purposes of ecosystem modelling approaches or for assimilation of observation based surface fields.

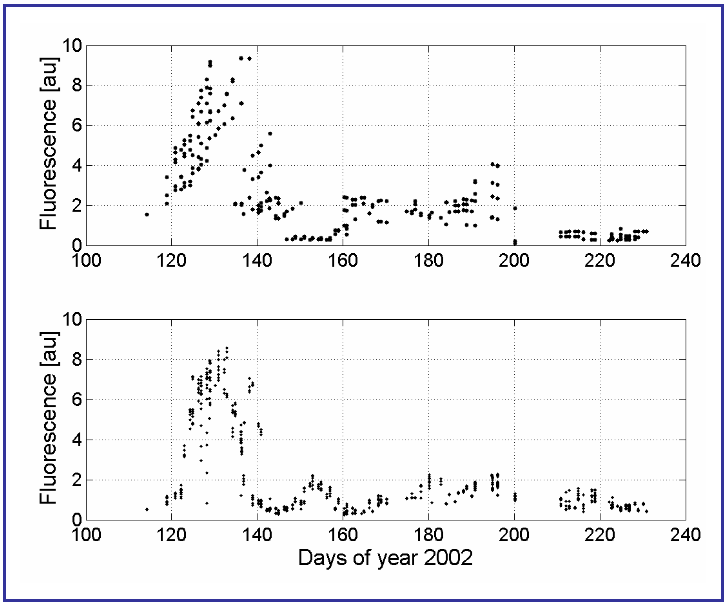


Figure 3-12: Comparison between observed FerryBox Chl Fluorescence (lower panel) and estimated chlorophyll for tracers starting from Gabbard and drifting to the FerryBox route (upper panel).

The present study is therefore focussing on methodical aspects to resolve and display the fate of water measured with a FerryBox and compared to data obtained with other methods.

Figure 3-11 and Figure 3-12 show the improvement of comparisons between FerryBox observations and those from other methods due to the application of the proposed model system.

6.3.5.3 The Use of FerryBox Data in Assimilation Schemes for Coastal Models

The assimilation schemes are principally grouped as sequential and variational methods. We will present one example regarding the sequential method. More detailed information on the results obtained with the data assimilation methods is presented in D-5-2 and some papers (see compilation in the Annex).

Sequential Estimation

Generalization of *Linear Estimation Theory* for *nonlinear* estimation led to the *Extended Kalman Filter (EKF)* (Jazwinski, 1970). In its formulation, it is assumed that the *nonlinear* observation and model operators can be approximated by their Jacobians if both the background and the analyzed state of the system lie close enough to the true state of the system.

Approximations of the EKF have been successful in some cases (Fukumori and Malanotte-Rizzoli, 1995). Nevertheless, an article written by Evensen (1992) pointed out that this method could lead to unbounded instability of the error, due to linearization of the error covariance propagation equation. In that same article, Evensen concluded that the use of the full EKF would require either extensive data coverage able to control the instability, or some higher order closure equations that damp it. In a latter publication, Evensen (1993) showed the difficulty of handling open boundary conditions in the treatment of the approximate error evolution equation. He then proposed an alternative method, capable of coping with the problems associated to the EKF in *nonlinear* systems.

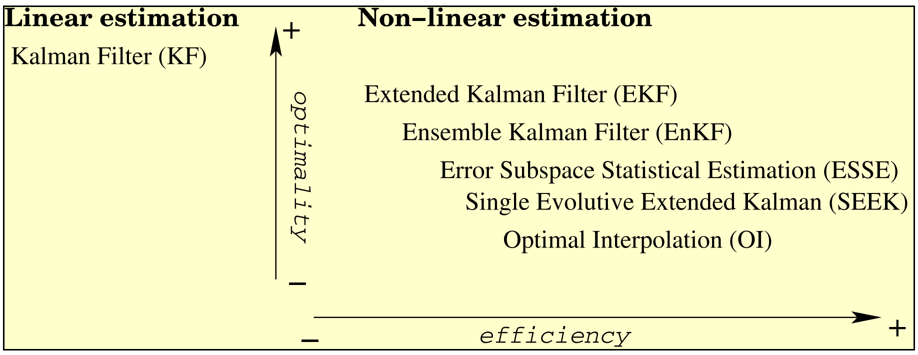


Figure 3-13: Schematic of different sequential methods. Methods are listed following their theoretical optimality and their efficiency (for given resources).

The alternative method proposed by Evensen(1994) was the Ensemble Kalman Filter (EnKF). In this scheme, the probability density function of the initial state is represented by an ensemble of initial states of mean equal to the best guess initial condition. Initial variance of the ensemble is set equal to that first guess estimated uncertainty. At each analysis step, the first and second order statistical moments of the system are estimated from the ensemble of states attained through integration of the initial ensemble (*a priori ensemble*).

Brusdal *et al.* (2003) discuss three ensemble based methods (Singular Evolutive Extended Kalman, Ensemble Kalman Filter and Ensemble Kalman Smoother) from the perspective of operational marine monitoring and forecasting systems.

Data Assimilation Schemes within the FerryBox Project

Two model setups were tested with different data assimilation schemes. One with the HCMR Poseidon model system for the Mediterranean, and one with the POL POLCOMS model for the Irish Sea.

An assimilation scheme based on the SEEK filter has been implemented into the Princeton Ocean Model which is the core of the POSEION pre-operational high resolution hydrodynamic model. The latter is a component of the POSEIDON operational and forecasting system that operates in the Aegean sea since 1999 (Nittis et al., 2001).

SEEK filter being a multivariate sequential assimilation method is an efficient tool for optimally handling observation data sets such as those (sea surface temperature and salinity) that were derived through the FerryBox activities at HCMR.

Two variants of the Kalman filter are coded into POLCOMS: 1. a simplified Kalman filter (Annan and Hargreaves, 1999) to assimilate sea surface properties, and 2. the EnsembleKalman filter (Evensen, 1994, 2003, 2004) to assimilate sea surface properties combined with available water column profiles. Both theses schemes are capable of assimilating FerryBox type data, i.e. irregular in space and time.

The model of HCMR has been first spun-up from climatology for a 3-year period (1999-2001) forced with the ETA atmospheric model 24-hour forecasts. A 2-year run of the model (2002-2003) was then performed in order to estimate the multivariate EOFs needed for the SEEK filter algorithm. Finally, an additional integration of 6 months (January –June 2004) initialized from the previous experiment constitutes the “free-run” of the model.

The time window chosen for the assimilation experiment extends from January-June 2004 during which SST, SLA and FerryBox SSS data products are available. In the assimilation runs, the rank of the filter’s covariance matrices was set to 60. The first 10 modes are evolved according to the system’s dynamics while the rest of the modes are kept invariant. For the localization of the filter gain, we have defined a radius of influence of 150 km outside of which the correlations are set to zero. The assimilation system assumes an accuracy of 2.5cm on the SLA data, 0.5°C on SST data and 0.08 on SSS data.

Table 3-2: RMS error (free run, forecast and analysis fields of the SEEK filter) on SSH, SST and SSS averaged over Jan-Jun 2004.

	Free run	Forecast	Analysis
SSH	5.17cm	4.20cm	3.32cm
SST	0.932°C	0.766°C	0.486°C
SSS	0.330	0.094	0.068

An evaluation of the behavior of the assimilation system is shown in Table 3-2 in terms of the RMS misfits between observational data and model estimates for the free-run and the forecast and analyzed fields as estimated by the filter. Regarding SSH, the filter analysis is almost 2 cm more accurate on average than the free-run.

The filter improves also the estimation of the model SST by 50%. Most significant improvement was obtained on the estimation of the SSS probably because of the daily availability of these data. Overall, the assimilation system was able to fit the data within the specified observational errors.

Time series of the RMS misfits for SSH, SST and SSS are presented in Figure 3-14. The forecast and analysis SSH misfits with respect to the observations generally follow the free-run errors but reduced by more than 20% and 35% respectively. Regarding SST (Figure 3-14(b)), the model free-run was significantly deviated from the observations toward the end of the assimilation window due to the model inability to correctly describe a strong warming event occurring in the Aegean Sea. The filter greatly enhances the behavior of the model and efficiently stabilizes the RMS error of both SST forecast and analysis during the warming period.

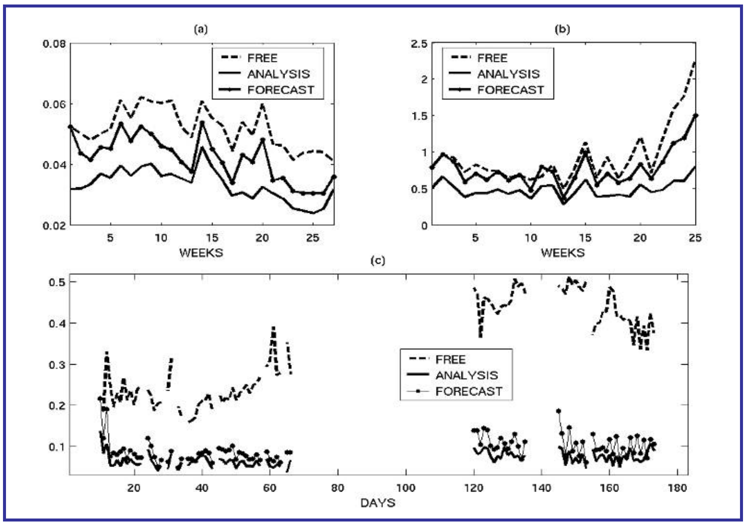


Figure 3-14: (a) RMS misfits (in meters) time series between the model SSH (free run, analysis and forecast of the assimilation system) and the altimetric data; (b) RMS misfits (in ^{o}C) time series between the model SST (free run, analysis and forecast of the assimilation system), and the AVHRR SST data, (c) RMS misfits time series between the model SSS (free run, analysis and forecast of the assimilation system) and the FerryBox SSS data.

Overall the results obtained so far with the assimilation system are very encouraging, but clearly call for further improvements in the model parameterizations and the assimilation scheme. As for the latter we believe that the assimilation system should be extended to the coarse resolution Eastern Mediterranean model which controls a large part of the errors present in the southern sector of the Aegean Sea model. Finally the definition of a realistic SSH climatology needed to convert SLA data to absolute signals remains open for near future studies.

In Conclusion

The examples presented here indicate that FerryBox data can have an impact on the performance of 3-dimensional models by reducing the RMS errors. However, both studies indicate that the influence of the FerryBox data on the solution is geographically limited to an area adjacent to the ferry route. The most positive value of the FerryBox data is that it is not constrained by atmospheric conditions, its availability being limited by ferry down time, unlike the satellite derived surface properties. This means that in more northerly latitudes at least with considerable cloud cover, the FerryBox provides considerably more useful data than satellites.

6.3.5.4 Remote Sensing Validation with FerryBox Data

Objectives

One of the objectives for WP-5 – 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, and to some extent also the Sea Surface Temperature. The results presented here are a compilation from D-5-4, which contains all details.

FerryBox data have the potential to contribute to the validation of satellite data due to 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 salinity (SSS) at the moment can not be measured from space.

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 a flow through FerryBox system sampling water below the surface at maybe 4-6 meters needs to be considered.

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. The only the problem of using one single depth which also is below the surface needs to be considered, but since the satellite products are based on an ocean colour signal which also has a contribution from below the surface the effect of the thin surface as for SST is not so predominant.

Chlorophyll-a Products Analysed from Water Samples

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. To explore this variability between the FerryBox partners a Chl-a inter-comparison was arranged, where also some laboratories outside the consortium were invited.

A total of 13 laboratories including the FerryBox partners, NIVA, FIMR, IEO, EMI, GKSS (2 laboratories), NOC and HCMR participated. Outside the consortium laboratories the following laboratories were included; SYKE in Finland, TARTU Laboratory in Estonia, PML in UK, EPA in Ireland and MUMM in Belgium. Details about the methods have been collected and included HPLC, fluorometric and spectro-photometric determination and different extraction techniques (Acetone, Methanol and Ethanol). 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 spectro-photometric 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 for FerryBox systems.

Chlorophyll-a Fluorescence and Chlorophyll-a

Chlorophyll-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. 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 WP 4 this has been investigated by comparing Chlorophyll-a from water samples 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/Chl-a fluorescence could be up to a factor 2. For other areas such large variation was not seen, but the seasonal variation was more predominant. Nevertheless this variation needs to be considered when fluorescence data are to be used for validation of the geophysical Chl-a product.

Turbidity and Total Suspended Material

The FerryBox measured turbidity is based on sensor data measuring the scattered light in the red part of the spectrum following the ISO turbidity standard, but some sensors use also blue light 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 effect any micro air bubbles that can be caused by pumping or air trapped in the FerryBox system. When the sensor data are properly converted to a Turbidity value one can investigate if the TSM/turbidity ratio is constant for the region covered by the FerryBox line. NIVA found in the Skagerrak that this ratio was relatively constant so by a simple conversion factor the sensor turbidity could be transferred to TSM.

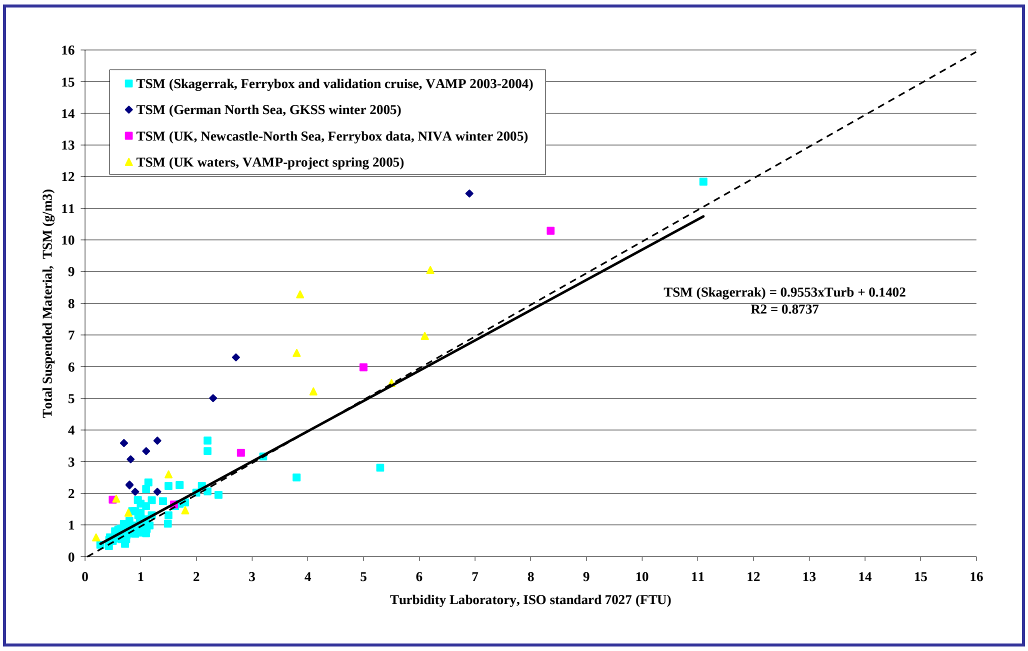


Figure 3-15: Relation between turbidity following the ISO 7927 standard and TSM measured according to the MERIS protocol.

Comparison of FerryBox Temperature and Satellite SST

Comparing SST with the FerryBox-determined temperature has not been much investigated in the project since proper equipment like an in situ radiometer measuring the real skin temperature has not been used or been available within the project. 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 while, 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 eliminate 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.

Comparisons of FerryBox Collected Chl-a and Satellite Chl-a Data

Satellite level 2 Chl-a (MERIS Algal Pigment Index) satellite data from the area around the ferry lines have been collected and prepared for such a comparison. Data has been collected at NIVA and in situ data from the FerryBox partners have been used in the comparison to see how such data can be used for validation.

Both FerryBox Chl-a fluorescence sensor data as well as water sample Chl-a have been collected from FIMR, EMI, IEO, NOC, GKSS, HCMR and NIVA. The comparison was done using the VISAT software, extracting the MERIS Chl-a products (Algal Pigment index I and II) along the ferry lines. The MERIS standard algorithm as well as Norwegian Chl-a algorithm (which is close to the new reprocessed MERIS data) was evaluated.

The ferries sampled in a variety of domains from high biomass areas in the Baltic with Cyanobacteria bloom to oligotrophic areas as found in the Mediterranean Sea.

In general the phytoplankton biomass trends along the FerryBox lines are well described and follow the satellite variability. Concerning the absolute values in Chl-a the variability between the in situ and satellite Chl-a are for some of the areas very high, especially for the complex areas of the Baltic. For the lower biomass areas where the phytoplankton distribution is more vertically homogeneous the comparison is better. The comparison also demonstrates the shift between Case 1 and Case II satellite products for the FerryBox routes that operate in the open as well as coastal high turbidity areas. To do a proper validation one needs to use Chl-a data based on water samples, and for the areas where this has been done and the “patchiness” in the phytoplankton is low the results are very promising. The reprocessed satellite data show better agreement for the Case 2 waters.

The FerryBox installed on the route between Cuxhaven (Ger.) and Harwich (UK) was not only used for the mandatory observations, but was also used to test the validation of remote-sensing observations with the observations made on the transect sampled by the ferry. Combination of these on-line observations with remote sensing can enhance the spatial resolution of the transect-related measurements for certain parameters such as chlorophyll-a and suspended matter.

One of the most important aspects of the relatively new *FerryBox* technology is its role in not only improving remote sensing products but as well fostering the understanding of marine processes.

The results shown in this paper reveals that the assimilation of *FerryBox* data along a transect with satellite observations increase the information value compared with the use of either of the two individual information sources. By using *FerryBox* systems on more lines crossing the area of interest on different tracks the information density about the water quality even could be significantly improved. In addition, by including the information about many other water quality parameters measured by the *FerryBox* (e.g. nutrients etc.) a much deeper insight in the processes controlling the water quality of coastal waters can be obtained.

Examples of the synergy between both operational measuring strategies are shown, both for large scale algal blooms in the North Sea as well as for local intense but short term blooms in the German Bight. Coherence of the data sets could be gained and improved by using water transport models in order to obtain synoptic overviews of the remote sensed and *FerryBox* related parameters.

Limitations of the currently used algorithms for deriving chlorophyll-a from remote sensing images for coastal and shelf seas (Case-2 water) are discussed, as well as depth related processes which can not be properly resolved on the basis of water intake at a fixed point. Since both methods used in this investigation are restricted to the water surface conventional monitoring methods by buoys and research vessels are still necessary at strategic locations. This will be necessary, for instance, to get information about the change of water constituents within the depth profile. However, in mixed coastal waters under normal conditions *FerryBox* data represent average conditions.

The lack of reliable temporal and spatial high resolved biological data hampered the assimilation into numerical models in the past. The value of a combination of ship-of-opportunity data with remote sensing can even be improved further by including numerical model data: The assimilation of these data with numerical models can be used to simulate the circulation of the water masses in order to fill the gaps between remote sensing and transect data in time and space. For instance, the disadvantage of the restricted availability of satellite data in areas such as the North Sea due to cloud coverage can be overcome by applying a numerical model with data assimilation which fills the gaps between the satellite passes.

This investigation showed already how important the hydrodynamic models in such strongly tidal influenced areas as the North Sea are for a comparison between different measurements with different spatial resolution at slightly different times. More research has to be carried out in this field, e.g., to include processes such as algal growth and degradation which may occur in the time span between the different measurements.

With the potentials of the *FerryBox* systems this situation could be improved in future and severe progress will be possible in marine ecosystem modelling resulting in an operational integrated monitoring system by data assimilation of in-situ data as well as remote sensing observations.

Further quantitative comparisons between FerryBox observations along the Ferry transect and satellite observations are presented in deliverable D-5-4.

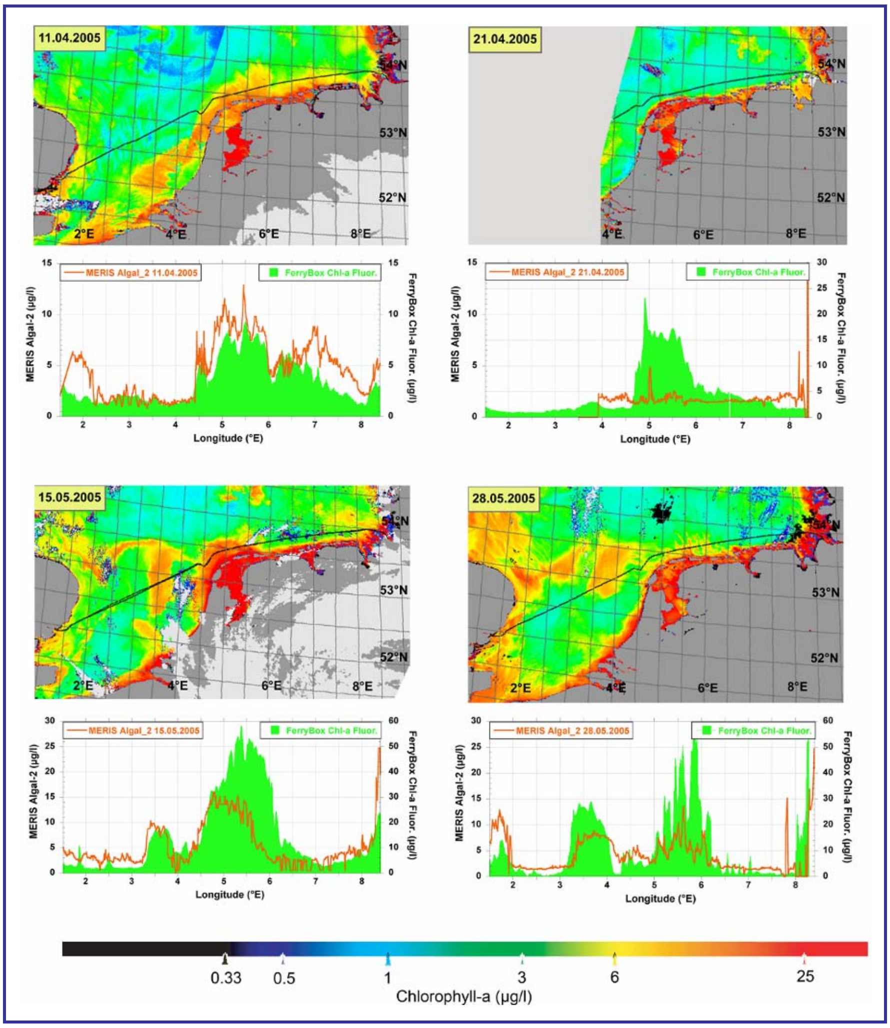


Figure 3-16: Examples of chlorophyll-a concentration derived from ENVISAT-MERIS (algal-2 for Case-2 water) for the North Sea (quality flags not obeyed) and comparison with extracted chlorophyll-a fluorescence from the FerryBox. Black lines show the tracks (not corrected for drift) of the ferry, (a) 11th of April, (b) 21st of April (c) 15 of May, (d) 28th of May.

6.3.6 WP-6 – Dissemination and Exploitation of FerryBox Results

In this work package the dissemination and exploitation activities of the project were clustered. The main goals comprised distributing information, experiences and results as well as stipulating the use of FerryBox systems in marine science and operational oceanography. In overall, the project gained a very high outreach both into the marine communities concerned as well as to the general public. Within this work package a comprehensive Technological Implementation Plan ("FerryBox T.I.P." – Section 4 of this report) was compiled and implemented to which one is referred for further details.

All project partners intensively communicated results and experiences on various scientific and technical conferences meetings. These are summarised in a comprehensive list of publication and dissemination activities which is delivered together with other results from this work package (D-6-3). In addition and right after completion of the funded phase, the FerryBox partners will elaborate a publication series with key results which is to be published in a peer-reviewed scientific journal with high outreach into the targeted user communities.

A complete inventory of scientific and technical publications, theses, conference contributions, presentations and poster presentations was compiled and assembled as a supplementary deliverable (D 6-3). Parts thereof are also included in Section 2 of this report.

Within follow-on activities it is the intention to keep the communities and public informed on publications and interesting presentations which will be announced and, where possible, also published on the FerryBox website and portal (http://www.ferrybox.org).

6.3.6.1 FerryBox Cost Benefit Estimate

A "FerryBox Cost Benefit Estimate ("FerryBox CBE") was elaborated to inform interested users and institutions intending to apply FerryBox systems with information on scientific and operational oceanography benefits and also giving reasonable breakdowns of cost and efforts necessary for appropriate implementation and operation. This document has been classified as "Public" for gaining a wider outreach and to support future applications of FerryBox systems in marine science and monitoring. A synopsis and the main conclusions of the FerryBox CBE are included in Chapter 6.5 below

6.3.6.2 FerryBox Websites and Online Data Services

The project has set-up a public FerryBox website and portal (http://www.ferrybox.org) informing on progress and results achieved during the project. This website may also facilitate as a portal to thematically associated websites, web pages and/or information services operated by the project partners. The site will remain operative after the project's funded phase for a period of at least 2 years and will be maintained and updated according to available resources.

Throughout the project all operators of FerryBox systems have established new or upgraded already existing individual websites, web pages, data retrieval and/or public information services for their individual system applications. An inventory of the FerryBox websites and web-based data services which were established, upgraded and maintained throughout the project is provided together with short contents descriptions direct links thereto in Table 3-3 below. [7]

[7] Table 3-3 gives the status of and links to the FerryBox websites at the end of the project. Websites, contents and links may be changed, supplemented or shifted to other services along with future activities and FerryBox applications. This information will be kept up-to-date on the FerryBox project and network website (http;//www.ferrybox.org) for a period of at least 2 years after close-out of the European FerryBox project.

Table 3-3: Synopsis of and links to the FerryBox web sites established and/or upgraded throughout the project.

The corporate FerryBox Project website was established and maintained throughout the project and beyond by HYDROMOD. The site informs on project activities, partners, planned and ongoing project work, results and other FerryBox related matters of public interest. It also functions as a portal to the websites of the project partners and especially to the web pages of the FerryBox operators.

The site will be updated by the final project results and is also intended to keep alive for several years along with the planned FerryBox network.

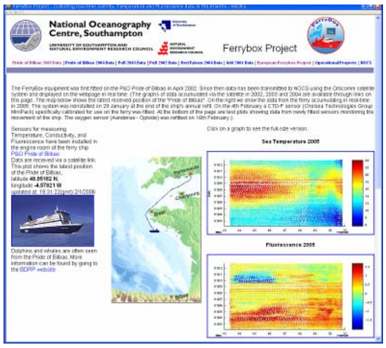
URLs: http://www.ferrybox.org
http://www.ferrybox.net
http://www.ferrybox.com
http://www.ferrybox.de

The Institute of Coastal Research and Operational Systems of GKSS maintains the web site of the German FerryBox project, a nationally funded complementary initiative which contributed to the European FerryBox project. The site provides information on the German FerryBox systems and links to the European FerryBox Project and affiliated activities world-wide. GKSS operates an online database for their FerryBox data. Users can generate graphs and registered ones can also extract numerical data.

URLs: http://coast.gkss.de/projects/ferrybox (web site)
http://ferrydata.gkss.de (FerryBox data server)

The National Oceanography Centre (NERC.NOC) has established dynamic FerryBox web pages and data services which provide comprehensive information on the FerryBox systems operated by the centre. Users can view graphs and animations, generate data plots and also retrieve track information Quasi-real-time and finally processed numerical data can be extracted from an online database without access restrictions.

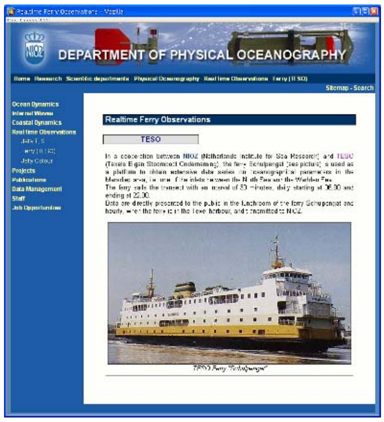
URL: http:/www.noc.soton.ac.uk/ops/ferrybox_index.php



The Netherlands Institute of Sea Research (NIOZ) publishes general information about the institute's FerryBox activities on the Den Helder – Texel ferry route.

A web-based service which provides data and more detailed information regarding the FerryBox measurements of NIOZ is accessible for registered users.

URL: http://www.nioz.nl/nioz_nl/
9d47a8435be9d28bba07efb502044ac5.php



The Finnish Institute of Marine Research (FIMR) has integrated utilisation and presentation of their FerryBox measurements (simultaneously incorporated into the Alg@line system) into the Baltic Sea Portal web site.

Here the FerryBox measurements are routinely used for e.g. provision of warnings of harmful algae blooms, ice situations or presentation of marine and oceanographic conditions in the Baltic Sea.

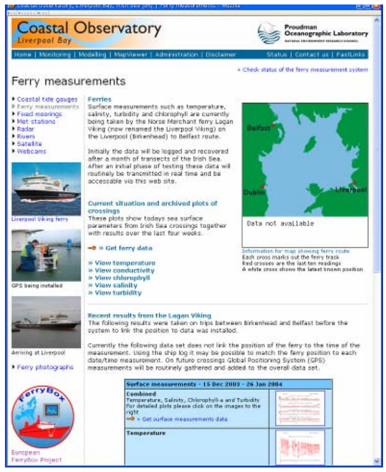
URL: http://www.fimr.fi/en/itamerikanta.html

The Proudman Oceanography Laboratory (NERC.POL) has integrated their FerryBox web pages and data services into the web pages of the POL Coastal Observatory.

Here NERC.POL informs on their FerryBox application across the Irish Sea, the actual status of the ferry and the measuring system and also provides graphical displays of measurements.

FerryBox data are available for registered users.

URL: http://coastobs.pol.ac.uk/cobs/ferries/



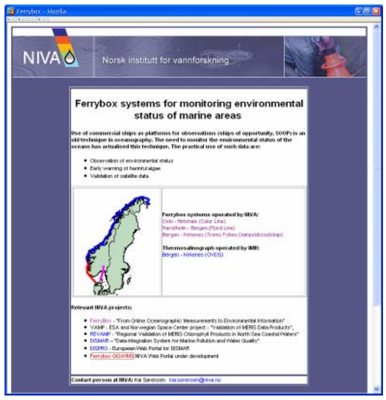
The Norwegian Institute for Water Research (NIVA) runs a series of web pages informing on their different FerryBox applications and routes including the Oslo _ Hirtshals route which contributed directly to the FerryBox project.

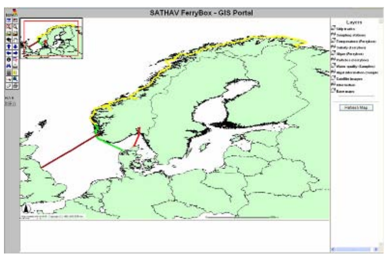
On the title page of each ferry route further information and data are provided. For 3 routes it is possible to retrieve real-time information on the ferry position as well as the most actual data and status information through satellite links directly from the ferries.

An interactive WebGIS application which also includes hazard predictions and warnings is presently under development an online as a beta-version.

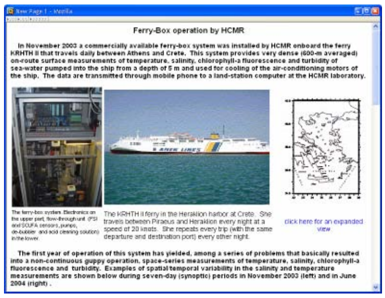
On-line services for data retrieval are established for users. (It is not restricted at the moment).

URLs: http://www.niva.no/ferrybox
http://www.ferrybox.no





The Hellenic Centre for Marine Research (HCMR) has established a web page which provides information and data examples from their FerryBox on the Athens – Heraklion route.



The page is included into the web site of the POSEIDON System, the Greek marine monitoring, forecasting and information system.

URL: http://www.poseidon.hcmr.gr/ferrybox

The Estonian Marine Institute (EMI) has established a FerryBox website (in Estonian language) in cooperation with the Estonian Marine Academy (EMARA) which informs about their project involvement and the FerryBox application across the Gulf of Finland (jointly operated with FIMR). The site also provides some sample data displays.

URL: http://www.emara.ee/ferrybox

The Chelsea Technology Group (CTG) has established FerryBox web pages which give information on the FerryBox systems, sensors and peripherals produced by the company.

Here also technical articles, product information and specification sheets are provided for downloading.

URLs: http://www.chelsea.co.uk/FerryBox.htm
http://www.chelsea.co.uk/TechPapers.htm#ferry

6.3.6.3 Recognition and Pilot-Application in the User-Community

The widely spread and intensive exploitation and dissemination activities in the FerryBox project already led to sound recognition and considerations in the user communities. Direct proves for this are e.g. the installation and operation of a FerryBox system by the Dutch North Sea Directorate/Rijkswaterstaat on one of their research, monitoring and work vessels in spring 2005, the order of a FerryBox system of the Swedish Meteorological and Hydrological Institute, the decision to successively install FerryBox systems on German research vessels, or the installation of FerryBox systems on two ferry lines between Tallinn and St. Petersburg and between Poland and Sweden which are both planned for becoming operative in 2006. The German Maritime and Hydrographic Agency (BSH) will conduct a pilot-project starting in 2006 in the German Bight. Three additional FerryBox systems were set up by organisations in Norway which has already implemented FerryBox systems as a key-component in the countries' monitoring approach. The first one is installed on a route (operated by Fjord Line) between Hanstholm (DK), Bergen (NO) and Newcastle (UK), the second one on a ferry running between Bergen and Kirkenes (operated by Troms Fylkes Dampskibsselskap) and the third one runs also between Bergen and Kirkenes and is operated by the Institute of Marine Research. These activities clearly show the great interest in these systems.

6.3.6.4 Broad Outreach into Scientific and End-User Communities

Already from the very beginning of the project presentations on the FerryBox project were given. Early presentations were specifically within the framework of operational services, environmental agencies, ICES, and (Euro)-GOOS. A series of presentations and posters were presented at the 2002 Third International EuroGOOS conference in Athens: Building the European Capacity for Operational Oceanography. Again at the 4th EuroGOOS conference in 2005 in Brest (France) a series of presentations by partners of the FerryBox project were given in a specifically dedicated session.

Apart from these, conferences on operational services contributions were given to major scientific conferences such as on the 2005 ASLO Summer Meeting in Santiago de Compostela, Spain where a special session with 15 contributions was held on the use of FerryBox systems. Several partners gave also presentations in North and South America and across Asia (for a complete list of presentations and exploitation activities deliverable D-6-3).

The project gained a strong outreach in Europe and world-wide through scientific exchange visits and international collaboration. For instance presentations were given in North and South America (e.g. in Brazil, USA, Canada) as well as across Asia (e.g. in China, Japan, Taiwan, Indonesia). Also the high outreach was achieved towards scientific and technical organisations and initiatives as for instance ASMO, EGS, IEEE, PACON (to mention just a few). Some of these activities already led to project proposals and even to funded projects expected to commence in short-time.

6.3.6.5 Public Awareness

A specific activity at first developed and implemented on the Dutch ferry between Den Helder and the island of Texel is an on-line display presenting FerryBox data on board to the passenger areas embedded in other interesting information during the trip. Thereby a large public community gets insight in currents, current directions, water temperature, salinity and phytoplankton density. The whole is combined with several explanations. This contributes to the understanding of the sea in a general sense.

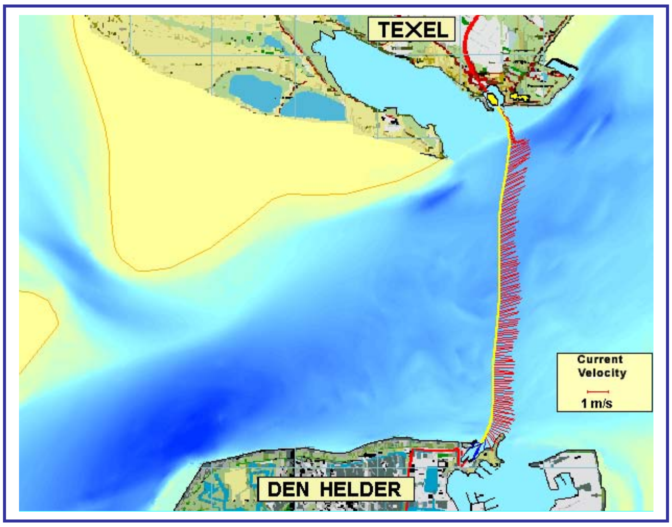


Figure 3-17: Example of a real-time display of current vectors along the ferry track between the island of Texel and Den Helder as typically displayed in the passenger area.

Plans exist on Norwegian ferries to offer similar displays comparable to those presented on long intercontinental flights in aircrafts. Meanwhile passenger display units are also available as add-ons to commercially available FerryBox systems.

6.3.6.6 Transfer to the Marine Industry

Europe has two major instrumentation and system manufacturers which have FerryBox systems and components in their portfolio of products. One (CTG – Chelsea Technology Group in UK) was a partner in the project and the other one (-4H- Jena Engineering GmbH in Germany) closely cooperated with GKSS in further developing a marketable FerryBox product and system line. Along with the project FerryBox systems and sensor packs as well as periphery like onboard displays became more advanced and market ready. Also service providers using FerryBox data (like the project partner HYDROMOD) had considerable benefits from their engagement in the project. Besides direct and indirect transfer of know-how and technology, the FerryBox project together with the outreach of its consortium contributed significantly in improving market positions and competitiveness of these European companies.

Some oil companies also showed interest in supporting FerryBox applications especially for oil-in-water monitoring with new non-standard sensors.

6.3.6.7 Exchanging Experiences beyond the Funded Project Phase

The FerryBox project partners will continue to keep their network and collaboration together and alive. It may also be enlarged with other interested parties. Some networking activities like occasional meetings and keeping the FerryBox website and Internet services alive are considered to be coverable by own funds of the partners for a limited period of time.

However, a series of reasonable activities cannot be conducted without contributory funding and consequently the project partners will seek for complementary opportunities, for instance under the European Operational Oceanography Cluster in the Sixth and Seventh RTD Framework Programmes of the European Commission.

6.4 Deliverables

The main deliverables of the project are compiled in Chapter 6.6 together with all the publications and reports produced. The most important deliverables however are listed in Table 4-1.

Table 4-1: List of main deliverables

D-1-2	Overview of the results of the first year
D-1-3	Overview of the results of the second year
D-2-1	Report on the functionality of the FerryBox systems
D-2-2	Report detailing the standard procedures on calibration and quality control procedures
D-3-1	Project data and information management plan
D-3-2	FerryBox project website
D-3-4	Completely processed and quality controlled data set for delivery to NODCs
D-4-2/3/4	Series of papers covering scientific issues studied with the help of the FerryBox system; eutrophication, sediment transport and water mass movement.
D-5-1	Paper describing contribution of FerryBox data to process understanding
D-5-2	Data assimilation schemes for FerryBox data in models; suitability of data assimilation schemes for use with FerryBox data.
D-5-3	Paper on value of assimilated FerryBox data in pre-operational models
D-5-4	Paper on the use of FerryBox data for validation of satellite data (paper 13)
D-6-2	FerryBox cost benefit analysis report (“FerryBox CBE” and paper 14)
D-6-3	Public summaries of results of FerryBox project Including a CD-ROM publication of several conference contributions, presentations, posters and allowed re-prints of scientific papers (D-6-3-A) an inventory of exploitation activities (D 6-3-B).

Instead of reports some results were drafted as scientific papers (see annexes to the report).

6.5 Conclusions Including Socio-economic Relevance, Strategic Aspects and Policy Implications

The socio-economic dimension of this project is estimated to be relatively large. This statement is based on the great interest the project has obtained in scientific and application oriented circles. Obviously oceanographic on-line data are important to estimate anthropogenic influences on coastal and shelf seas. An even larger socio-economic dimension appears when this information can be used to support land based measures for nutrient reductions (paper 11). Those who are modelling water transport or transport of specific compounds such as dissolved nutrients were generally very interested in using the data.

The scientific exercises done with the data regarding eutrophication status of European coastal waters will attract large interest from environmental agencies such as EEA, OSPAR and HELCOM.

Operational services which are linked under the umbrella of EuroGOOS have shown their interest by sending representatives to our meetings or by attending workshops where FerryBox data and results were discussed.

The final acceptance of this new method to improve operational monitoring of water quality parameters in Europe will also depend on the cost-benefit estimate presented as one of the deliverables of this project. We have been able to convince environmental and hydrographic services that FerryBox is a powerful and efficient alternative for current monitoring activities on the basis of this analysis.

The FerryBox Cost Benefit Estimate (FerryBox CBE) provides proven information on benefits and costs of FerryBox systems when applied for a wide range of applications in operational oceanography and routine monitoring of the oceans as well as for scientific applications. It summarises experiences gathered throughout the European FerryBox Project and a therein embedded period of routine operation of underway measurement systems on 9 ferry lines in 8 European countries and in rather different marine environments. In addition it incorporates information and experiences obtained in the national subprojects as well as from spin-off projects which emerged during the lifetime of the FerryBox project.

For this study we define FerryBox systems as such kinds of oceanographic underway measurement systems which have achieved a certain grade of maturity with regard to functionality, integration of technical components and application friendliness which allow them to be installed and routinely operated on ferries and other ships of opportunity. These systems provide enhanced ocean observing capacities in terms of increased spatial and temporal coverage of larger marine areas combined with relatively low installation and operation costs and efforts.

6.5.1 Scientific and Operational Benefits

The application of FerryBox systems shall be considered in two areas.

- Firstly as a versatile tool to contribute to a better understanding of marine processes, spatial and temporal variability for a wide range of scientific applications of which several ones have been demonstrated in the European FerryBox project. These comprised for instance process investigations on eutrophication, application into numerical models by specific means of data assimilation, sediment transport assessment, evolution and decay of algal blooms).

- Secondly, they should be considered as an integrated component in operational oceanography and routine monitoring of marine environmental conditions and water quality together with and complementary to other oceanic observing components such as fixed monitoring stations, space-borne remote sensing and research or monitoring cruises. At present such matured systems are limited to a relatively small – but for monitoring the most important – numbers of “standard” parameters such as water temperature, salinity, turbidity and chlorophyll-a fluorescence as well as automated water sampling for subsequent analyses onshore in the laboratory at the uppermost layer of the sea. However, a series of “non-standard” applications such as velocity profiling, acoustic backscatter or algae group demarcation have been tested in the project. Some of them have already reached pre-operational stages with foreseeable potential for introduction into operational systems.

For both the scientific and operational oceanography sectors matured FerryBox systems provide a series of benefits and a wide range of application possibilities.

FerryBox systems provide a very high spatial coverage which is impossible to achieve by other means especially in routine applications. Considering typical ship speeds between 15 and 20 knots and typical data acquisition cycles between 1 and 30 seconds a FerryBox system can resolve spatial features along the ship’s track with around 10 to 300 metres. This is sufficient for most processes and spatial scales relevant for ocean and coastal monitoring of the seas and for many scientific objectives (e.g. when compared with local Rossby deformation radii or typical eddy scales). This resolution even provides the ability to detect small-scale features as for instance oil or chemical spills if present.

The temporal resolution is moderate but compared to other “track-related” and spatial measurements still high. Typical repetition cycles of short-route coastal ferries are several times per day to several times per hour, for ferries across marginal seas cross typically once per one maximal two days and even for longer ferry lines a route is served several times per week. The fact that ferry lines are usually identically routed allows deviation of time series which is usually not possible for other en-route measurements as for instance by drifters or floats.

6.5.2 Technical and Operational Benefits

Compared to offshore deployed devices the operation costs and efforts of FerryBox systems are drastically lowered as these works can be conducted in one of ports the vessel is calling routinely which, however, should to be located nearby to the operating institution.

FerryBox systems do not need a specially designed platform and can be installed on almost all seagoing vessels providing their owners and operators allow it. Installation costs and efforts are relatively low as available infrastructure on the ship like space, water supplies, cable booms, and communication devices can be used supportively.

Many technical problems typical for stand-alone marine measuring systems can be entirely omitted. This includes especially constraints in availability of electric energy, installation and consumable storage space as well as protection of several components against harsh marine environments and prevention measures of longer-term fouling with associated maintenance efforts.

As the measuring device always “comes back to the operator” the need for special research and monitoring cruises for maintenance, servicing, in-situ sampling or longer-term sample preservation for calibration and reference means are obligate as this can be done in port. Samples can be taken from the system’s automated water sampler for subsequent laboratory analyses.

Consequently and in summary FerryBox systems and their sensors and components are much easier and simpler to design, construct and operate than stand-alone marine in-situ devices.

6.5.3 Other Benefits

FerryBox systems provide the opportunity to achieve a strong public outreach if accordingly applied and supplemented with associated equipment and functionalities. Attractive data and information displays in the passenger areas which can be combined with other information of interest (e.g. on the local environment, information for tourist and travellers, soft advertising) can be used for awareness creation and public dissemination.

Ship owners and operators as well as other public entities and private companies may be also included in such platforms and information services. By this the application of FerryBox systems can be strongly motivated and it is also possible to encourage direct or indirect contributions to installation or running costs.

6.5.4 Some Constraints of FerryBox Systems

However, we should not omit here to mention some constraints of FerryBox systems in relation to other monitoring and measuring means in marine science and operational oceanography.

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 good-will 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 interference by the crew.

Vessel operators may from time to time close-down services, alter shipping routes, or replace a vessel on short notice. Also ferries can be quickly sold or companies may close-down or change ownership. To cope with this Ferryboxes shall be highly mobile and a good relationship with the vessel's operator is required to maintain sustainable system applications. Especially when used for longer-term assessment and monitoring purposes the selected shipping route needs to be durably served.

The measuring depth of "standard" FerryBox systems is limited to the surface layer. Although some parameters are possible to acquire also over a certain depth range with advanced systems or special sensors or carrier systems the foreseeable routine applications are limited to the sea surface.

With regard to data quality one ought to keep in mind the use and purpose of the data. Therefore it is necessary to discriminate between lower quality data available in real- or quasi-real-time as typically applicable for warning purposes and quick assessments and with regard to achieving high-quality data sets which usually require additional quality-control and post-processing measures when for instance used for long-term assessment of environmental conditions, variability and changes as well as for most scientific investigations. Compared with other marine monitoring and measuring systems Ferryboxes acquire very large amounts of data. Hence quality control, evaluation and processing means need to be highly automated, robust and reliable. Therefore new measures in data processing and evaluation need to be developed especially when Ferry boxes are used routinely and in increasing numbers in operational services.

6.5.5 Tentative Estimates of Costs and Efforts

The costs for the instrumentation and the sensors as well as for their installation are relatively low as in many cases standard components can be used. Infrastructure which is already installed on the vessel (e.g. rooms, cable channels, water and energy supplies, communication equipment) can be used in support. Depending on system functionalities, sensor configurations, sampling equipment and other functions and capabilities of a FerryBox system the typical investment costs are in the range of 50,000 EUR for a "standard arrangement" to 150,000 Euro for a system with enhanced capabilities (e.g. with integrated ADCP, automated sampler and/or algae group sensor).

Installation and set-up costs certainly 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 10,000 to 20,000 EUR. More sophisticated installations for instance with hull mounted sensors or supported by a moon-pool can be usually made only when a vessel is refitted or new-built. Such installations cost typically several 10,000 EUR but may be supported by ship owner if he is interested (see below).

The same applies for installations in the passenger areas which display data and associated information of interest which typically range from around 5,000 to 10,000 EUR (excluding specific programming and multi-media developments).

Operation costs of FerryBox systems include following components: Servicing and maintenance, calibration and referencing, system operation and control, data quality control, pre- and post-processing plus archiving up to a stage "ready to use for applications".

The main cost factors are personnel efforts which along with the FerryBox project have been experienced in the range of about 3 to 4 person months (cumulative for scientist, technicians and support staff) per operational system. A considerable optimisation potential exists when an institution operates routinely more than one FerryBox system of identical or similar configuration as related operation and maintenance efforts will not increase linearly with the amount of systems.

Associated estimates from, however still few experiences are in the range of an increase by a factor of 0.5 for each additional system. Associated are costs for typically consumables, travels and communication which are very much application dependant and summed up in average to 5,000 to 10,000 EUR per year. On long ferry routes the main cost factor are satellite communication fees. However, large ferries and passenger cruise liners have intensive and routine satellite ship-shore / shore-ship communication traffic and if the FerryBox system can hook on to this the communication costs for control and data transmission become marginal if not negligible and might be covered in support by the vessel's operator. As for every measuring system also the replacement costs for the FerryBox system ought to be accounted under 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 10,000 to 30,000 EUR per year should be calculated therefore.

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 expectable that FerryBox systems become more standardised as well as easier to install, calibrate, maintain and operate. In overall this might lead to cheaper system costs and diminished efforts for their operation.

6.5.6 Conclusions and Recommendations

The European FerryBox Project as a whole and the FerryBox CBE in particular proved the benefits and versatility for application and utilisation. FerryBox systems comprise a versatile and cost-efficient component of ocean observing systems and can be also used for a wide range of scientific objectives.

The future requirements in marine environmental monitoring and operational oceanography as demanded by the Global Observing System (GOOS) and its regional implementation initiatives but also by several policies as in Europe the Water Framework Directive (WFD) are likely impossible to achieve. Without FerryBox systems as an integrated supplementary component in ocean and coastal observation systems the required capacities, improvements and enhancements of spatial and temporal coverage cannot be gained for relatively low costs or even without cost increase.

Existing monitoring and warning systems can be optimised with appropriate applications of routine underway measurements. For developing countries which have to build-up marine observing capabilities and capacities along with implementation of the GOOS as well as for monitoring their territorial waters and exclusive economic zones (EEZ) FerryBox systems are a cost-efficient alternative.

Agencies and administrations involved in operational oceanography and marine environmental monitoring and management are encouraged to deeply consider the potential and use of FerryBox systems along with further development of operational oceanography services.

Also a series of activities and objectives in marine science, earth observation and climate change and impact investigations are hard if not impossible to achieve without increased utilisation of ships-of-opportunity and automated underway measurements.

Table 5-1: Overview and relative ranking of FerryBox Applications

Overview on and Relative Ranking of FerryBox Applications Compared with other Marine Measurement Methods				
Observation methods, application areas and focused goals	**Ferry / VSOP**	**Single point mooring / ODAS buoy**	**Remote sensing**	**Research / monitoring cruise**
Scientific applications				
Temporal resolution	+	+ +	0	--
Horizontal spatial resolution	+	--	++	0
Vertical resolution	-	+ +	-	+ +
Flexibility for application to new scientific topics	+ +	+	- -	+ +
Environmental monitoring				
Regional information	+	--	+ +	+
Time resolution	+	+ +	0	-
Long term availability	+	+	+	+
Public awareness	+ +	-	+	-
Costs	+	-	0	- -
Number of parameters	+ +	0	0 / -	+ +
Maintenance	+ +	+	0 / -	0
Data availability in time	+	+ +	0 / -	+
Policy support				
Observation methods, application areas and focused goals	**Ferry / VSOP**	**Single point mooring / ODAS buoy**	**Remote sensing**	**Research / monitoring cruise**
Long term effect monitoring	+	+ +	0	0
Proving implementation success/progress	+	+	+/-	+
Costs for proving	+ +	-	+	- -
Relative ranking scheme	++ very applicable / suitable or low costs and efforts	0 indifferent or not applicable / suitable or not accessible for this type of application		- - less applicable / suitable or high costs and efforts

This in particular in times of tough public budgets with associated constraints in research vessel capacities and availability. The marine science community is also encouraged to increasingly transfer experiences, laboratory prototypes, metrologies and evaluation methods into the applied oceanography sector and to the marine industry.

The marine industry community is encouraged to develop higher automated, more modular, less maintenance intensive and more user-friendly devices towards, ideally, plug-and-play Ferry boxes. To become commercially attractive this needs to be stimulated by increasing amounts of applications which will, in return, strengthen the technological lead, competitiveness and market position of European equipment manufacturers and service providers.

Ship owners and operators are encouraged to team up with FerryBox operators (and vice-versa) and to utilise the indirect benefits and potentials when allowing the installation of systems on their vessels.

FerryBox systems provide an excellent area for promotion activities and an attractive in-kind service for their customers and passengers. If appropriately initiated win-win-situations between marine science, oceanographic agencies, manufacturers, service providers and the shipping industry can be easily achieved. Increasing applications of FerryBox systems will also stimulate development of additional applications and utilisation of data. The European FerryBox Project has depicted some possibilities but might have likely only scratched the surface regarding future potentials of Ferry boxes.

The strategic dimension of the FerryBox is in our view much wider: application of this technique on a larger more global scale would enable science as well as society to get informed about the dimension of global change in the oceans. Therefore a network of ships-of-opportunity is needed which covers on a regular basis our oceans collecting not only data on the parameters which can be measured nowadays but also of CO_2 (Schneider et al., 2006) and maybe selected types of pollution. With these types of data long term trends in the oceans could be detected easier because of the higher data density, both on a temporal as well as on a spatial scale. Thus we would be informed earlier when changes in the oceans occur, enabling mitigation at an earlier stage and therefore at lower costs.

6.5.7 Dissemination and Exploitation of Results: Conference Contributions

As shown before dissemination of results has been an ongoing task within the project. The first conference contribution was at the Athens 2002 EUROGOOS conference where a complete poster presentation on FerryBox was given, immediately after the official start of the project.

At the EUROGOOS conference in Brest (2005) a complete presentation of FerryBox results was presented through posters and oral presentations, one which was adopted for the plenary meeting.

The 2nd Annual meeting of the FerryBox project held at the National Oceanographical Centre in Southampton in 2004 contained a series of presentations and a wide variety of posters on subjects related to FerryBox. To raise awareness and outreach of the project external partners were invited to attend the meeting. All contributions will be listed together with the ASLO 2005 meeting where another special FerryBox session was held. They will be presented in Deliverable D-1-4, where all the references are listed.

For the ASLO 2006 summer conference a special workshop is planned where again several contributions from the project will be shown.

During the ICES Annual Science Conference in Tallinn (2003) a workshop was held with FerryBox contributions as well. Through contacts with the user community within GOOS and ICES strong links have been set up for the exchange of information.

6.6 Recommendations for Future FerryBox Applications

6.6.1 The Role of FerryBoxes for Coastal and Shelf Sea Research

As discussed above, 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.

Automated systems on ferries or ships of opportunity will play a major role in the near future for ocean and shelf sea observations. In this context, especially the investigation of coastal and shelf seas with their large spatial heterogeneities and temporal variabilities will gain very much from these systems. An obvious reason is that coastal zones are intensively exploited and shelf regions are highly productive fishery areas, from which about 95 per cent of the world's commercial catch is taken. In addition, shallow sea areas are easily accessible for marine mining, primarily for oil and gas exploitation, but also for gravel and sand as construction materials. Finally, the coastal seas are becoming increasingly important for transportation and as recreation areas.

Therefore, marine environmental science should establish observing systems for a better assessment of these areas. This will require investigations for understanding processes in coastal ecosystems as well as supervision and management of the coastal environment, in order to be able to assess the status and changes of ecosystem components. For many of these tasks automated systems on ferries and ships of opportunity are an important new technology.

Events in shelf seas are influenced by atmospheric forces, interactions between land and sea, and through exchange processes with the deep ocean. These are further affected by local factors such as regional geology, coastal morphology, bottom topography, heat-, freshwater-, and material flux from the land and atmosphere, as well as larger-scale phenomena such as wide-ranging atmospheric fields, climate fluctuations, oceanic circulation, or processes in the watershed regions.

The transitions from shallow, near-coastal areas to the deeper distant regions of the shelf seas, and from there across the shelf break out to the open ocean, are characterized by strong physical and biogeochemical gradients that exhibit large spatial and temporal variability due to the multiplicity of external driving mechanisms. These processes have to be observed on much faster timescales and with improved closer spatial resolution, for which ferry systems are an ideal supplement to stationary networks of buoys and research vessel cruises.

6.6.2 Operational Applications

At the time being, automated measuring systems from ferries and ships of opportunity are at the “brim of operational application”: Following a EUROGOOS definition (from: Prandle, D and N C Flemming (eds) (1998) “The Science Base of EuroGOOS”, No. 6, Southampton Oceanography Centre, Southampton. ISBN 0-90417530-8) operational oceanography is the activity of routinely making, disseminating, and interpreting measurements of the seas, oceans and atmosphere so as to:

- Provide continuous forecasts of the future condition of the sea for as far ahead as possible - forecasting
- Provide the most useful accurate description of the present state of the sea including living resources – nowcasting
- Assemble climatic long term data sets which will provide data for description of past states, and time series showing trends and changes – hindcasting

Operational applications for monitoring of coastal and shelf seas will increase within the next decades. In addition, many global climatical aspects are covered: Both oceanic and atmospheric scientists have endeavoured in recent decades to get a grasp on seasonal to decadal changes in the ocean, sea ice, and atmosphere. Their goal is to gain sufficient understanding of the processes involved to develop and run models of the complex interactions among climatic components. Initial results have been obtained through internationally agreed deployment of in-situ measurement procedures, satellite-supported remote sensing, and model simulations.

In these applications FerryBox systems will play a major role in the near future.

FerryBox systems, in general, are just right for temporal dense measurements on a transect. Their limitations are in the measurement of surface waters. Depending on the draught of the ship and on the location of the water intake only mixed waters of the upper 2-5 m of the sea are recorded.

6.6.3 Measurement Technology

6.6.3.1 General

The results of oceanographic research are made possible by technical advances in measurement systems. Despite the fact that the technology for long-term measurements at moored stations has improved very much in the last decades, this is mainly valid for relatively simple physical sensors such as temperature and salinity. Sensors are the critical interface between the buoy system and the environment, and are probably the most important part of an ocean observing system.

The major limitations to these measurements are biofouling. At the time being, most sensors for the detection of chemical and biological parameters do not have the required stability and robustness for long-term unattended application on buoys etc. For example, optical sensors such as fluorometers for chlorophyll measurement or turbidity meters for the assessment of suspended matter concentrations require frequent cleaning and to prevent biofouling problems. Here one of the advantages of FerryBox systems is their great possibilities of automated cleaning, sufficient power supply and a relatively clean environment (little mechanical stress). Because the sensors are a critical component of the total measuring system, modifications have to be directed toward longer application times and greater dependability. In the future, increased efforts should be directed towards new optical, chemical and acoustic sensors.

In addition to assuring the necessary accuracy, robustness, low maintenance, and dependability over long-term deployment times on ferries, international standards for the instruments and procedures employed also need consideration and agreement. This insures that data from different sources are quantitatively comparable and can be utilized as combined data sets in models. The FerryBox project has been a good example for such “adjustment” of protocols and measuring procedures.

In addition, the development of technologies, such as FerryBoxes, obtainable at reasonable costs (in contrast to very expensive buoy networks) is essential. FerryBox applications are also required for the calibration, validation, and correction of remotely collected satellite data. These include sensors for radiation measurements and to enable atmospheric corrections.

6.6.3.2 Tested Measurement Technologies

Within the FerryBox-Project several physical/chemical/biological parameters for which reliable sensors already exist have been identified according to their usefulness for scientific applications and monitoring.

Among these parameters are Acoustic Current Profilers (ADCPs). Long-term high-frequent ADCP observations in tidal-influenced waters ensure, for example, that the different tidal components that contribute to the observed signal can be analysed in detail revealing information on three-dimensional transport and mixing of water bodies. The possibility to assess suspended sediment concentrations and sediment bedloads together with the current fields enable for the first time to estimate the budget of transported sediments through a tidal inlet. In the future the accuracy of these measurements will increase by improving the software algorithms for an assessment of suspended matter (“inverse models”).

Parameters which yield information about the eutrophication status and which were successfully assessed in the FerryBox project are chlorophyll-a (fluorometer), oxygen, pH and nutrients.

The scientific value of oxygen measurements is based on the fact that oxygen is an indicator for processes such as phytoplankton growth and decay.. This is not the case for the widely used fluorescence measurements to estimate changes in biomass. Fluorescence is taken as a measure of chlorophyll but due to change in plankton type and photo-physiology of the plankton chlorophyll to fluorescence ratio and the fluorescence yield can vary widely in time and space.

Measurements of nutrients have two functions in a GOOS context. One is in determining the concentrations of nutrients that are immediately available to support primary production in a given area, the other is to provide information that can be used to help understand the short and long range transport and biogeochemical processes that control the supply of nutrients throughout the year. A range of autonomous analysers have been tested within the FerryBox project that have successfully transferred wet chemical methods from the laboratory to remote measuring stations, e.g., FerryBoxes. Nevertheless, further improvements are needed.

Among the relatively recent developed sensors are systems for the determination of pCO2. This parameter not only provides information for an assessment of the regional and global carbon budget but is helpful as well for specific local eutrophication processes. More information can be found in Deliverable D-2-4 Non-Standard Sensors.

6.6.4 Harmful Algae Blooms (HABs)

A broad spectrum of events comes under the category of harmful algal blooms (HABs) that have a negative impact on human activities. Harmful algal blooms involve a wide diversity of organisms, mechanisms of impact and bloom dynamics. Gaps in scientific knowledge and lack of adequate technology constitute a major hindrance to the improvement of observational capabilities and progress in predictive understanding of these phenomena. An effective HAB operational monitoring system should include a long-term, global, observing network for phytoplankton species composition and related physical, chemical and biological variables, coupled with an array of models and statistical tools and sustained by an effective data management system. Expected products encompass different temporal scales of prediction and levels of benefit. Early warning of HAB events allows us to put in action specific contingency plans 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, in a very cost-effective and reliable way.

6.6.5 Recommendations

For the FerryBox technology “the future” has already begun: During the FerryBox project several governmental monitoring agencies (The Netherlands, Finland and Norway) already included this technology into their operational monitoring program. Other authorities, e.g., in Germany, consider the application in the near future. It was agreed that all FerryBox partners contact their proper authorities and encourage the implementation of the FerryBox technology. For a better acceptance the scientific results of the FerryBox project are a good example for its application.

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

1. In the planning phase a careful assessment should be carried out to judge if 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 has a combination with buoys to be considered?
2. 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 D2-3 “Interim report on the experiences with the FerryBox during operational use”.
3. 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. More details can be found in deliverable D-2-4 “Report on Non-Standard Sensor Trials”.
4. The effort/expenditure of the maintenance that depends on the number and type of measured parameters should be carefully observed. More details can be found in deliverable D-6-2 “Cost-Benefit Estimation Report”.
5. 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 bimonthly, depending on instrumentation and required accuracy) are needed.

6.7 References to Section 6

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6.8 Annex – Drafts of Scientific Publications

1. Estimating suspended sediment concentration and transport from a ferry mounted Acoustic Doppler Current profiler
    a. L.M. Merckelbach, 2005. A model for high-frequency acoustic Doppler current profiler backscatter from suspended sediments in strong currents. Submitted to Cont. Shelf Res.
    b. L.M. Merckelbach and H. Ridderinkhof, 2005. Estimating suspended sediment concentration using backscatterance from an acoustic Doppler profiling current meter at a site with strong tidal currents. Ocean Dynamics, DOI 10.1007/s10236-005-0036-z
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