FerryBox and Automated Ships of Opportunity as Operational Tools for Ocean Observing Tasks

F.Colijn[1], W. Petersen[1], F. Schroeder[1], S.Kaitala[2], K. Sørensen[3], D. Hydes[4]
[1] *GKSS Research Centre, Institute f. Coastal Research, Geesthacht, Germany*
[2] *FIMR, Helsinki, Finland*
[3] *NIVA, Oslo, Norway*
[4] *NOC, Southampton, United Kingdom*

Introduction

Global and regional changes in physical and ecological states of marine systems, often caused by human activities, directly affect the safety and well being of human populations. Coastal marine and estuarine ecosystems and human populations are especially vulnerable to the negative impacts of these changes (UNESCO 2005).

Within the GOOS initiative the global module is primarily concerned with improving marine weather forecasts and marine services, predicting basin scale oscillations (e.g. the ENSO, PDO, NAO), and predicting decadal scale climate changes (e.g. global warming and sea level rise). The coastal module is primarily concerned with establishing an observing system that provides data and information required to mitigate and manage the effects of natural hazards (e.g. tsunamis, tropical storms), climate change (e.g. sea level rise, warming) and human activities (e.g. land-use practices, extraction of natural resources, shipping) on coastal systems and their capacity to sustain goods and services of value to human society.

In order to understand the main processes and to detect harmful trends early enough an observing system comparable with the World Weather Watch would be required even though it will be much more complex (UNESCO 2005).

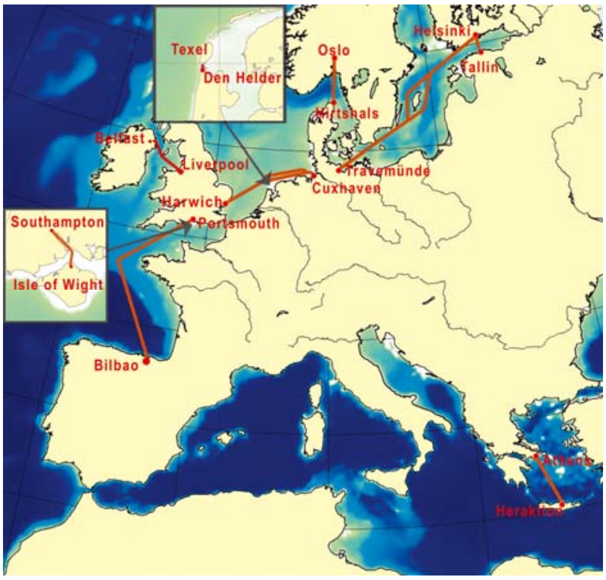
Thus a clear need exists to improve our observational capacities; not only on standard physical parameters such as temperature and salinity, but also on chemical (nutrients) and biological (phytoplankton, zoo-plankton) parameters This could be used for the validation and calibration of models and could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

The lack of monitoring systems that provide continuous observations of the marine environment, especially in coastal areas and shelf seas is a serious hindrance to the understanding of marine systems. Currently, operational monitoring is mainly carried out by manual sampling and analysis during ship cruises. Autonomous measuring systems on buoys allow measurement of standard oceanographic parameters (temperature, salinity, currents) and in some cases other parameters, e.g., turbidity, oxygen and chlorophyll fluorescence. However, existing observations mostly lack the spatial coverage and temporal resolution required to determine the state of the marine environment and changes within it. Furthermore the automatic systems on buoys etc. are affected by biofouling and the operational costs are high due to ship costs needed for servicing.

To overcome these problems, the use of “ships of opportunity” (SoO) has been promoted by EuroGOOS (Fleming et al. 2002) and other organisations. There are many routes for ferryboats and other SoO which run frequently repeated routes. The "Continuous Plankton Recorder (CPR)" [Reid et al. 1998] has followed the idea of using scientific equipment on such ships for continuous recording of environmental data. Over the last 60 years it has produced a impressive data on plankton abundance with time (e.g.Vezzulli & Reid, 2003). As a measuring platform ferries or container ships on regular routes offer a cheap and reliable possibility to obtain regular observations on near surface water parameters. Applying such a FerryBox system on ferry boats or ships-of-opportunity has several advantages: (1) the system is protected against harsh environment, e.g. waves and currents, (2) bio-fouling can be more easily prevented (inline sensors), (3) no energy restrictions (in contrast to buoys), (4) easier maintenance when ferry comes back "to your doorstep", (5) lower running costs since the operation costs of the ship do not need to be calculated, (6) instead of point measurements (buoys) transects yield much more information

Since the techniques to apply ferries are quite recent and have not yet been used extensively, an European project called "*FerryBox*" (2003-2005) had been initiated in which water quality monitoring systems on "ships of opportunity" were being tested and applied. Nine ferry routes were used in order to compare different systems and environments (Figure 1).

The project encompassed the oligotrophic eastern Mediterranean Sea to hypertrophic Northern European estuaries.



The aims and objectives of the project were:

- to show how *FerryBoxes* can be used for automatic measurements of environmental parameters,
- to quantify environmental variability on a European wide scale addressed to eutrophication, sediment transport and transport of water masses,
- to improve the quality of numerical models by assimilation of *FerryBox* data,
- to demonstrate the reliability of such systems for monitoring the marine environment at all times of the year and
- to recommend to the European marine community how future *FerryBoxes* can be operated

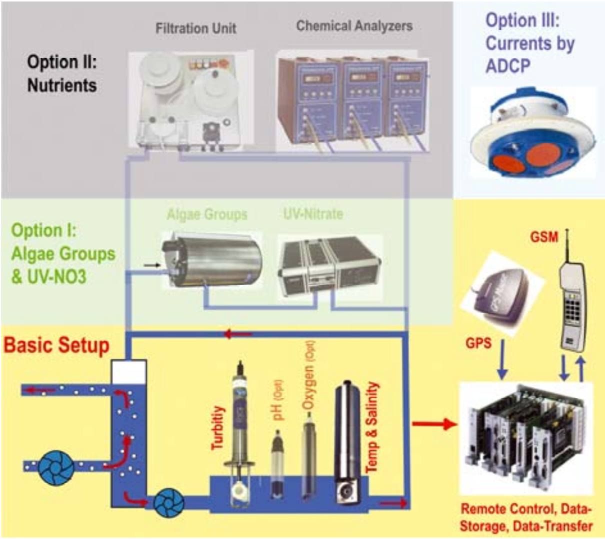
Fig. 1: Routes within the EU project "FerrxBox"

Technical Setup

The technical setup of a FerryBox consists of an autonomous measurement and data logging and transmission system which operates continuously while the carrying ship is underway. Measurements are made using in devices which are either in direct contact with or sample from a continuous flow of seawater. The principles of such a flow-through system are schematically shown in Figure 2: For an unattended operation the system is controlled via position (by GPS) and an internal computer. The system is connected to a station on shore via GSM or satellite for remote control and data transfer.

The water intake is at a fixed depth, normally between 1 and 6 meters depth. A separate water intake point can be used or a sully from one of the internal water flows of the ship. The seawater is pumped into the ship from an inlet (often in front of the ships cooling water intake). A debubbling unit removes air bubbles, which may enter the system during heavy seas. The basic sensors were turbidity, temperature & salinity and chlorophyll-a fluorescence. In some cases an oxygen sensor (Clark electrode or oxygen optode) and pH sensors were applied as well. The basic setup was extended to further non-standards sensors such as an optical nitrate sensor and algal group detector as well as chemical analysers for nutrients. In this case the water had to be filtered before analysis in order to measure only the dissolved nutrient fraction. One FerryBox (Den Helder,Texel) was operated with an ADCP in order to observe water current velocities as well as sediment transport in a tidal inlet. In some systems an automatic refrigerated water sampler was installed in order to collect seawater at predefined positions for subsequent analysis in the lab (nutrients, phytoplankton composition). A detailed description of the different systems and their functionalities has been documented in deliverable D-2-1 of the EU FerryBox project report (www.ferrybox.org).

One of the tasks within the project had been to test the reliability of the systems for operational applications. The failure rate depends very much on the type of sensor: "standard sensors" such as water temperature, salinity, chlorophyll-a fluorescence and turbidity are more reliable than complex sensors such as nutrient analysers. As an example the availability of the FerryBox data in the Skagerak (Data from NIVA) in year 2004 is shown in Figure 3.



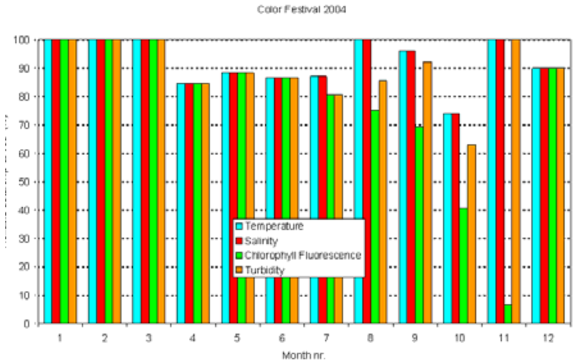


Fig. 2: *Principle design of a FerryBox flow-through system*

Fig. 3: *Plot of the availability of reliable data for the Norwegian ferry route in 2004 (NIVA)*

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

Problems of Biofouling:

For high reliability of the data and long-term stability of a FerryBox system the problem of biofouling had to be solved. The biofouling problems can only be avoided by frequent cleaning of the system in particular at times of high biological activity. This can be achieved either by regular manual cleaning of the system or by implementation of effective automatic cleaning procedures. For example, in the North Sea an automatic self-cleaning system was implemented. It prevents biofouling by cleaning specific sensors with tap water under high flow and rinsing the whole system with acidified water after each cruise. This procedure improved the long-term reliability of the data drastically. By these measures the long-term stability of sensors such as salinity could be prolonged up to one year without maintenance and manual cleaning. This self-cleaning principle was also implemented in one industrial version of the FerryBox (Figure 4) already operated in different countries.

Fig. 4: Industrial version of a FerryBox (4H-Jena, Germany)

Application of FerryBox data

1. Relations between winter nutrient concentrations and algal blooms in summer

A method for establishing a numerical index (indicator) to summarise annual variations in plankton bloom intensity and duration in different sea areas was tested. Such an index has the potential to be used by organisations such as the European Environment Agency as a management tool. The procedure tested is based on work by FIMR (Fleming and Kaitala, 2005). A simple numerical index is calculated to describe the magnitude of the spring bloom. This is an integration of the variation in concentration of chlorophyll over the spring bloom period in different regions and this is compared to the amounts of nutrient present at the end of winter. The key to its use as management tool is understanding the degree to which the index can be taken as a measure of eutrophication because it is proportional to the amounts of nutrient present at the end of winter. Figure 5 shows the spring phytoplankton bloom index against the geometric mean of the maximum winter nutrient concentrations for the Baltic Sea and the Atlantic. A general relationship between a high plankton index and higher concentrations of nutrients does exist. However further work needs to be done to refine the idea. The figure reveals that in the Baltic there is a wide variation in the index and its relationship to concentrations of nutrients from year to year suggesting that a degree of caution should be taken into account when trying to make judgements on the basis of data from a single year. In contrast to the Baltic Sea and the Atlantic such clear relationships could not be observed in the compiled data set for the North Sea transect. This poor relationship may stem from the availability of light and advection controlling biomass rather than simply nutrients in this region.

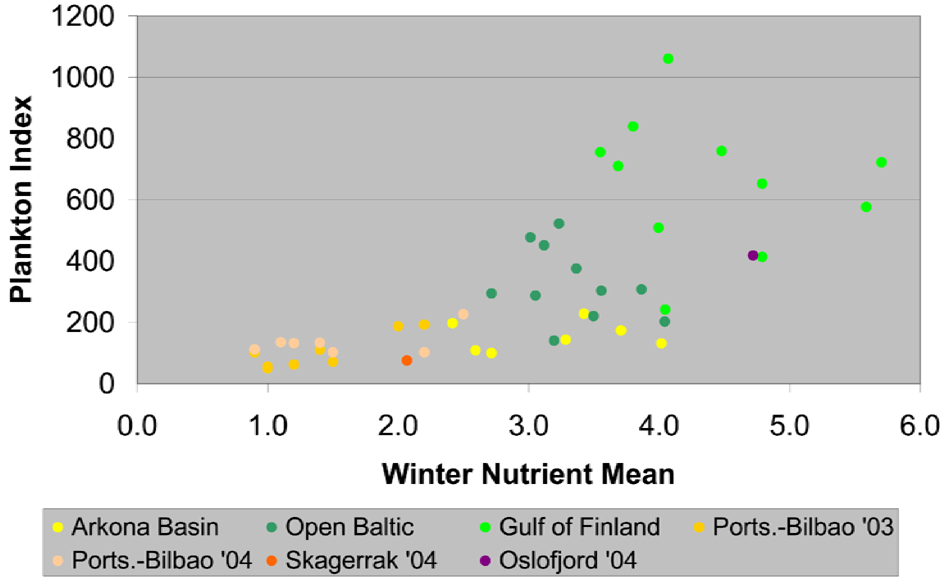


Fig. 5: Plot of the spring phytoplankton bloom index against the geometric mean of the maximum winter nutrient concentrations for results from the Baltic (Gulf of Finland, Open Baltic - and Arkona Basin) in 1992-2004 and Portsmouth to Bilbao in 2003 and 2004.

2. Classification of water masses

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

As an example of how different regions in areas along a FerryBox route may be defined both in terms of FerryBox data and local knowledge, Figure 6 shows the FerryBox route in the Skagerak (left panel) including existing knowledge of current flow patterns. The flow patterns correspond well with the measured salinity by the FerryBox in January 2004 (K. Sørensen, unpublished data).

3. Oxygen dynamics in coastal waters

Changes in the concentrations of dissolved oxygen are determined by changes in the temperature of the water and biological production and respiration. The biological changes are relatively large and easily measured while changes due to temperature can by calculated from well established information. As the FerryBox programme was being developed both improved Clark type electrodes and the newer optode became available so that oxygen could be measured routinely as part of a FerryBox system.

This enabled the project to compare estimates of biological production based on oxygen measurements with the more common use of chlorophyll-fluorescence as an indication in changes in phytoplankton biomass. As an example figure 7 shows the observations of pH and oxygen together with the chlorophyll-a fluorescence along the transect in the Southern North Sea (Cuxhaven Harwich) in spring 2005 (Petersen et al. 2005)

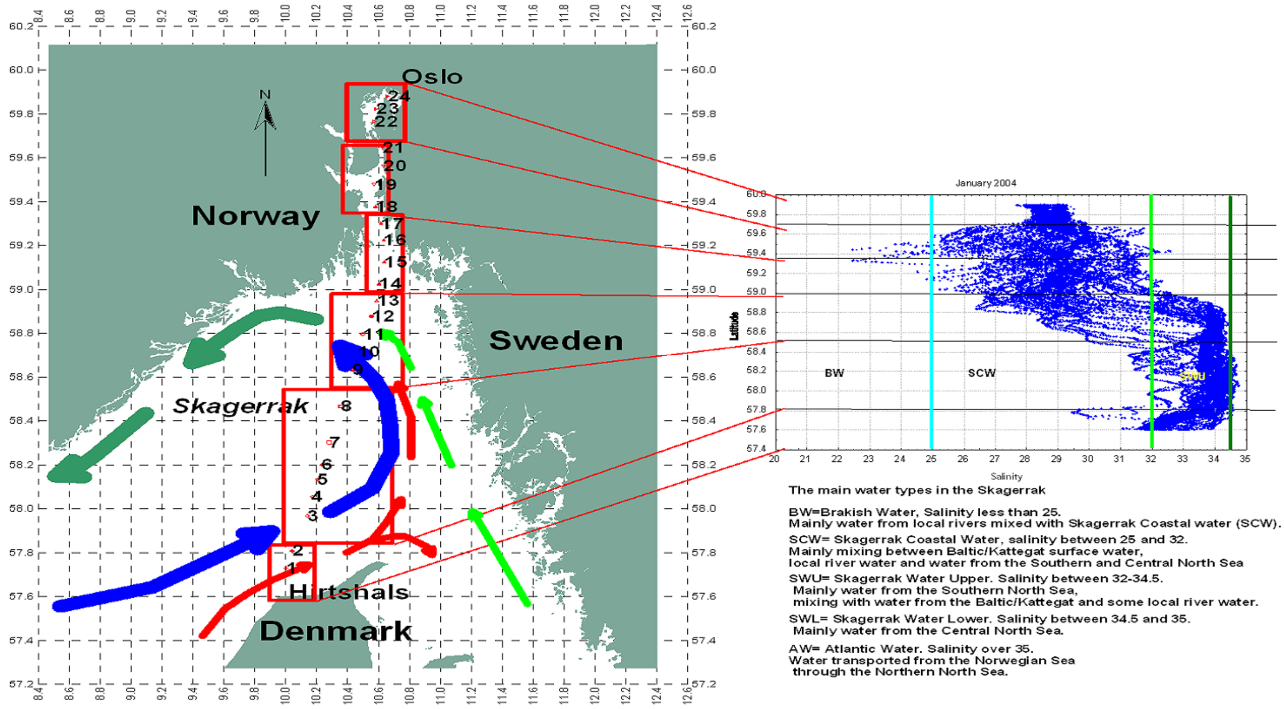
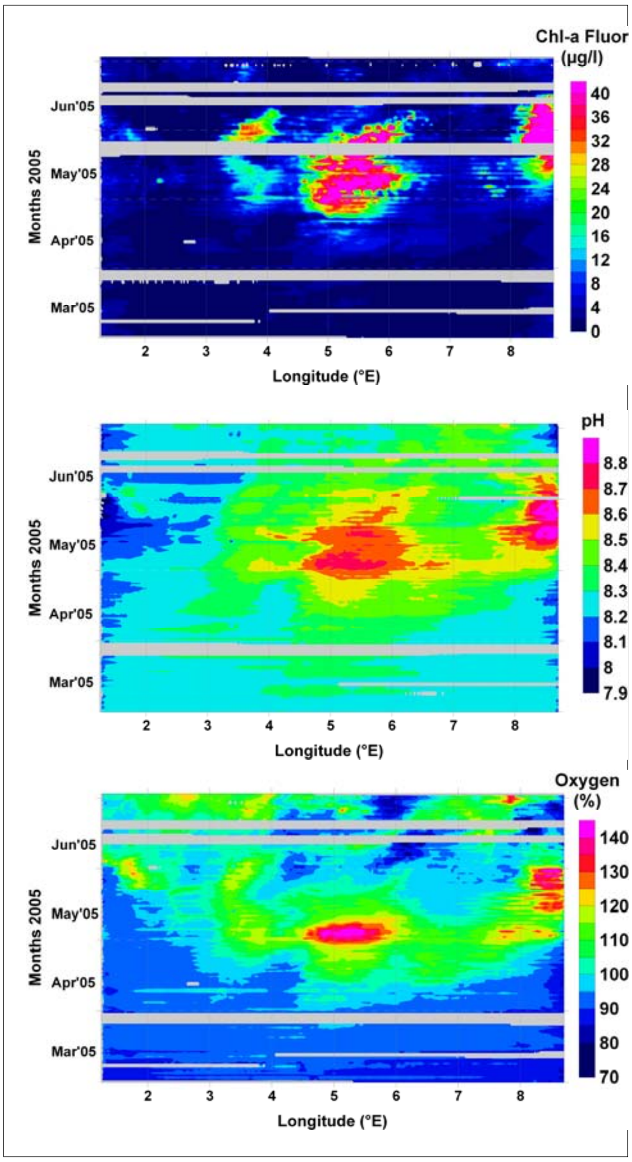


Fig. 6: *Classification of different regions in the Skagerak*



In fig. 7 the pattern of the three figures looks similar. High algal activity (measured by the chlorophyll-a fluorescence) starting along the Dutch coast (between 4.5°E to 6.5°E) at mid of April with a maximum at mid of May and diminishing in end of May corresponds well with the pH maxima and the high oxygen over-saturation. Later on high algal activities are detected in the Elbe estuary in the German Bight (8.2 to 8.7°E). However, in detail the relation of chlorophyll-a to pH and oxygen looks sometimes different. For instance at late June in the region influenced by the English Channel (2°E to 3.5°E) high oxygen saturations does not correspond with the chlorophyll fluorescence and pH values at that time. This behaviour may be explained by stratification of the water column and biological production. In the summer biological production and chlorophyll are located at the thermocline. These waters are too deep to be sampled by the FerryBox. However oxygen produced as the plankton grow diffuses in towards the surface and is detected by the FerryBox.

Fig. 7: *Chlorophyll-a fluorescence, pH and oxygen (saturation index)observations along the transect in the Southern North Sea (Cuxhaven-Harwich) spring 2005*

Conclusions

The *FerryBox* system is a new operational tool using ferryboats and other SoO as carrier platform for automated monitoring equipment. The experiences within the EU project demonstrates that such systems can cost-effectively deliver reliable high frequent data improving conventional monitoring strategies.
The results demonstrate the applicability of the *FerryBox* system for better understanding and assessing the ecosystem and the underlying biogeochemical processes in the marine environment. By combination with remote sensing images (Petersen et. al.2006) and together with hydrodynamic transport models the ‘one-dimensional’ view along a transect of the ferry can be enlarged to a more spatial view. 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.

Acknowledgements

This work was supported by the European Commission under the 5th RTD Framework Programme, Contract no: EVK2-CT-2002-00144. We would like to thank all involved partners.

Literature

Flemming, N.C., S. Vallerga, N. Pinardi, H.W.A. Behrens, G. Manzella, D. Prandle, J.H. Stel, 2002. Operational Oceanography: implementation at the European and regional seas. Proc. Second International Conference on EuroGOOS, Elsevier Oceanography Series Publication series 17.

Fleming V. and S. Kaitala (2005). Phytoplankton spring bloom intensity index for the Baltic Sea estimated for the years 1992 to 2003. Hydrobiologia 554, pp. 57-65

UNESCO 2005: An Implementation Strategy for the Coastal Module of the Global Ocean Observing System. GOOS Report No. 148; IOC Information Documents Series N°1217; UNESCO 2005.

Petersen, W., Colijn, F., Elliot, J., Howarth, M.J., Hydes, D.J., Kaitala, S., Kontoyiannis, H., Lavin, A., Lips, I., Pfeiffer, K.D., Proctor, R., Ridderinkhof, H. and K. Sørensen (2005). European FerryBox Project: From Online Oceanographic Measurements to Environmental Information. In: Dahlin, H., Flemming, N.C., Marchand, P., Petersson, S.E. (eds) European Operational Oceanography: Present and Future. Proceedings of the 4th EuroGOOS Conference, Brest (France); ISBN 92-894-9722-2

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

Vezzulli, L. & Reid, P.C. (2003). The CPR survey (1948-1997): a gridded database browser of plankton abundance in the North Sea. Progress in Oceanography 58: 327-336

Reid, P.C., Edwards M., Hunt H.G. and Warner A.J. (1998). Phytoplankton change in the North Atlantic. Nature, London. 391. 546