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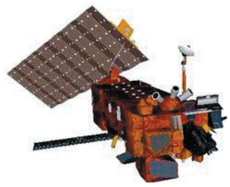

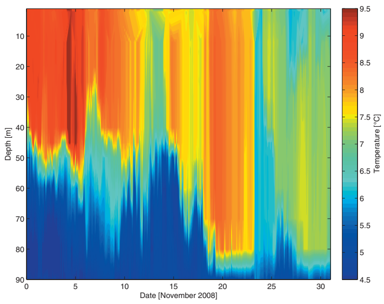

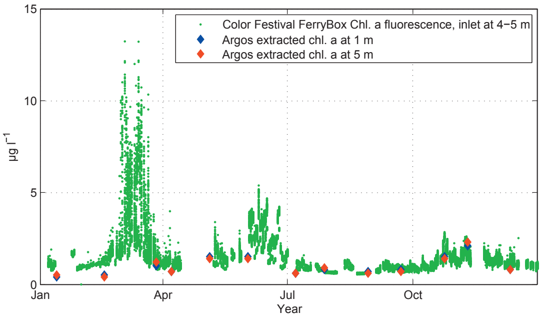

Infrastructure for marine monitoring and operational oceanography

Bengt Karlson
Philip Axe
Lennart Funkquist
Seppo Kaitala
Kai Sørensen

RO
No 39, 2009

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Year: 2009

Title: Infrastructure for marine monitoring and operational oceanography

Authors: Bengt Karlson, Philip Axe, Lennart Funkquist, Seppo Kaitala and Kai Sørensen

Illustrations on front page:

Top	EnviSAT with the MERIS sensor, European Space Agency.
Upper left	The SMHI instrumented buoy Läsö E. and the ship R/V Argos. Photo by Bengt Karlson.
Upper right	SMHI and FIMR are installing a FerryBox system on the merchant ship TransPaper. Photo Transatlantic AB.
Lower left	The diagram shows temperature as a depth and time profile at the Huvudskär E. buoy in the Baltic proper. A short term event of lowered temeprature is illustrated.
Lower right	Chlorophyll a fluorescence from the NIVA FerryBox system between Oslo and Hirtshals in the Skagerrak as well as chlorophyll a data from sampling by R/V Argos. The spring bloom was observed using the ferrybox but not by less frequent sampling using the research vessel.

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Infrastructure for marine monitoring and operational oceanography

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CONTENTS

PREFACE

In September 2008 SMHI was commissioned by the Swedish Environmental Protection Agency to analyse and evaluate different types of systems for pelagic marine environmental monitoring and for development of indicators (agreement number 223 0819). The result is this report. The content of the report is solely the responsibility of the authors and does not necessarily reflect the opinions of SMHI, NIVA or FIMR. We are very grateful for the advice we have received from several persons during stimulating discussions during the work. The help with data and figures is appreciated. Are Folkestad and Jan Magnusson at NIVA and Fredrik Waldh, Lars Andersson, Lars Axell, Bertil Håkansson and Elisabeth Sahlsten at SMHI are among those to whom we owe thanks.

Data originates mainly from the Swedish National Marine Monitoring programme, the Alg@line programme at FIMR and the FerryBox programme at NIVA. NIVA and FIMR participated in the EU FP6 project FerryBox. Some of the data presented is part of that project result. Additonal data is from the project SatOcean funded by the Norwegian Space Agency and the VAMP project funded by the ESA-PRODEX programme.

January 2009

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SUMMARY

Automated systems for observing physical, chemical and biological conditions in the sea are being implemented worldwide as part of the Global Ocean Observing System. This report describes their use in the Baltic and the Skagerrak-Kattegat areas. An evaluation of the use of FerryBox systems in the waters around Sweden shows that the quality of data from near surface waters is high, and that the frequent sampling makes possible observations of short term phenomena such as algal blooms. These events are often overlooked by infrequent sampling using research vessels, which leads to erroneous estimates of phytoplankton biomass, ecosystem carrying capacity etc. Data come from the Helsinki-Lübeck route, operated by the Finnish Institute for Marine Research and from routes in the Skagerrak-Kattegat operated by the Norwegian Institute for Water Research. FerryBox data were compared with data from traditional sampling, principally from RV Argos operated by SMHI, but also from the HELCOM databank at ICES.

Observations using automated systems such as satellites, stationary platforms (buoys and piles) and FerryBox systems may contribute substantially to improving the quality of results from models describing the physical and biogeochemical conditions in Scandinavian waters. Boundary conditions for models can be obtained using measurements in the eastern North Sea and in the Skagerrak, while data assimilation from a network of buoys, FerryBox-systems and research vessels improves the quality of model results. Today, between four and six automated oceanographic observation systems are in operation in Swedish waters, which can be compared to more than 700 for meteorological purposes. A dramatic increase in the number of observations is necessary for effective data assimilation. To make the observations useful for biogeochemical models, parameters such as inorganic nutrients, phytoplankton biomass and oxygen must be added to the basic parameters salinity and temperature.

A detailed proposal for a new infrastructure for marine monitoring and operational oceanography in Sweden is put forward. FerryBox systems should be operated in collaboration with institutes in Finland, Estonia, Poland, Germany, Denmark and Norway. Coastal buoys contribute to the monitoring needs of the EU Water Framework Directive while offshore buoys are for long term climate and ecological research and for fulfilment of the EU Marine Strategy Directive . Products combining satellite data with in-situ observations should be developed. These automated systems augment monitoring using research vessels but do not replace it. SMHI, the Swedish Institute for the Marine Environment, the Swedish Water Authorities, the Swedish Environmental Protection Agency, Swedish Navy, Coast guard, Maritime Administration and Board of Fisheries are proposed to govern and operate the system, with SMHI as the lead partner. The function ‘National data host for operational oceanographic data’ is proposed, to be established at the National Oceanographic Data Centre at SMHI.

A number of indicators for describing the status of the pelagic environment around Sweden are proposed. Some already exist while some are new. New ones include indicators for acidification, changes in plankton community structure and physical climate indicators. Basin wide indicators are based on measurements using a combination of sampling platforms. Other indicators are more specific, e.g. for transport between basins and inflow of water to the deep basins of the Baltic Proper.

This report was commissioned by the Swedish National Environment Protection Agency

1 INTRODUCTION

1.1 General introduction

The waters surrounding Sweden, i.e. the Baltic Sea, the Kattegat and the Skagerrak are under severe environmental stress due to anthropogenic input of nutrients, toxins etc. from the catchments' area where more than 85 million persons live (HELCOM-area only). Also global climate change and material transported by air to the area are influencing the aquatic environment as well as activities such as fishing and the traffic of merchant vessels. In addition natural long term processes are changing the environment, e.g. the transition from the last ice age to the present situation.

Sweden is making a considerable effort to contribute to the restoration of the Baltic and the Kattegat-Skagerrak. Part of the effort is to monitor changes in the pelagic environment, i.e. the free water mass. The present marine environment monitoring programme is in part based on the level of attainment in the seventies when HELCOM and OSPAR were established. New knowledge of the processes in the sea and new monitoring techniques has since been developed. Recently the use of ferries for monitoring surface waters in Europe attracted the attention of the journal Science (Fig. 1, Ainsworth, 2008). Also new demands from society change the requirements towards reporting the status fast and cost efficient. This report is about improving the monitoring to detect changes and also to understand the processes occurring in the sea better. Implementation of the proposals made in this report will hopefully form a base for a cost efficient measurement programme. The data produced will also be useful for other purposes than long term marine monitoring, e.g. for energy efficient marine transport, marine safety, warnings about oil spills, algal blooms etc.

At the end of most chapters internet links to information relevant to the chapter is found. References are found after the chapters. A list of acronyms with explanations is found at the end of the report for the convenience of the reader.

1.2 About the area

1.2.1 Physical description

The Baltic can be described as a large estuary with surface salinities near zero in the northernmost part and about ten in the south. The water is stratified and the salinity in the deep water is about 13 psu. The Kattegat and the Skagerrak are more marine with surface salinities c. 20-30 psu. Tidal amplitude is very low (<30 cm). Typical for both the Kattegat and the Skagerrak is that the water column is strongly stratified during most or all of the year. Stratification is due to both salinity and temperature. The deep water salinity is about 34 psu in the Skagerrak. Seasonal water temperature variations are quite large, i.e. c. 0-20 °C. In the deep basins in the Baltic hypoxia is common and ice cover is normal every winter in the northern part.

1.2.2 Climate change

The changing climate is likely to have several different effects on the marine environment. One is change of the precipitation in the drainage area of the Baltic and the Kattegat-Skagerrak affecting salinity and nutrient input etc. Another is changes in the carbonate system of the sea, .e.g. lowered pH will change the structure of the marine ecosystem in fundamental ways. Climate related environmental change is likely to be a major issue the coming decades. River run-off is likely to increase in winter causing increased inorganic nutrient load partly due to increased erosion.

1.2.3 Biological description

The salinity gradient from almost zero in the Bothnian bay to around 30 in the Skagerrak result in a transition from limnic species to marine species. In the Baltic euryhaline species are quite common. The number of species in the Baltic is in general much lower than in the Skagerrak-Kattegat. One effect of the intermediate salinity is that severals pecies live near their limit of distribution due to salinity stress. Also the diversity of species

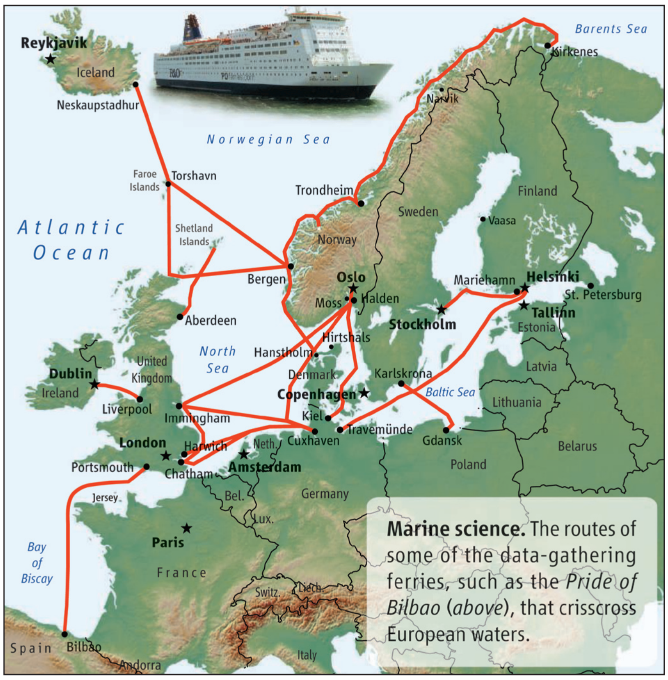


Figure 1. FerryBox systems in Europe were the subject of an article in Science (Ainswort, 2008).

in intemediate salinities is low compared to fully marine areas resulting in a more fragile ecosystem. Introduced species may have fewer predators compared to areas with with higher diverisity.

The pelagic ecosystem in the Baltic is heavily influenced by nitrogen fixing cyanobacteria that frequently form blooms in summer. These organisms do not grow at the higher salinities found itn the Skagerrak and the Kattegat. The main boundary is at the Sound (Öresund). An effect of the differences between the Baltic and the Skagerrak-Kattegat is that monitoring tecniques must be differnet due to the differences in the ecosystems.

1.3 Goals of marine environmental monitoring

1.3.1 National environmental goals

Sweden has set up sixteen environmental goals:

1. Reduced Climate Impact
2. Clean Air
3. Natural Acidification
4. A Non-Toxic Environment
5. A Protective Ozone Layer
6. A Safe Radiation Environment
7. Zero Eutrophication
8. Flourishing Lakes and Streams
9. Good-Quality Groundwater
10. A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos
11. Thriving Wetlands
12. Sustainable Forests
13. A Varied Agricultural Landscape
14. A Magnificent Mountain Landscape
15. A Good Built Environment
16. A Rich Diversity of Plant and Animal Life

The marine monitoring mainly addresses goals 1, 3, 4, 7, 10 and 16.

1.3.2 International conventions and treaties

Several international conventions and treaties govern the monitoring of the seas. Below the most important ones relevant to monitoring of the waters surrounding Sweden are described briefly.

1.3.2.1 EU Marine Strategy Framework Directive

The aim of the European Union's ambitious Marine Strategy Framework Directive (adopted in June 2008) is to protect more effectively the marine environment across Europe. It aims to achieve good environmental status of the EU's marine waters and to protect the resource base upon which marine-related economic and social activities depend. The marine strategies to be developed by each Member State must contain a detailed assessment of the state of the environment, a definition of "good environmental status" at regional level and the establishment of clear environmental targets and monitoring programmes.

1.3.2.2 EU Water Framework directive

The Water Framework Directive (WFD) includes coastal waters. The aim of WFD is long-term sustainable water management based on a high level of protection of the aquatic environment. A key issue is good ecological status. A substantial monitoring effort is needed to fulfil the requirements of the WFD.

1.3.2.3 EU INSPIRE directive

From the INSPIRE web site:
Directive 2007/2/EC of The European Parliament And Of The Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). The initiative intends to trigger the creation of a European spatial information infrastructure that delivers to the users integrated spatial information services. These services should allow the users to identify and access spatial or geographical information from a wide range of sources, from the local level to the global level, in an inter-operable way for a variety of uses. The target users of INSPIRE include policy-makers, planners and managers at European, national and local level and the citizens and their organisations. Possible services are the visualisation of information layers, overlay of information from different sources, spatial and temporal analysis, etc

1.3.2.4 HELCOM

Helsinki Commission, the Baltic Marine Environment Protection Committee, is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area. HELCOM includes the Baltic and the Kattegat. The legal base for HELCOM is the Helsinki Convention from 1974 (updated in 1994). The co-ordination of the monitoring of the sea is done in the Monitoring and Assessment Group (HELCOM MONAS). HELCOM adopted in ministerial meeting 2007 new action plan to guideline actions to mitigate environmental problems facing the Baltic Sea. One priority is to develop indicators to assess the extent to which ecological have been met

1.3.2.5 OSPAR

The OSPAR Convention is the current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. OSPAR include the Skagerrak and the Kattegat. Work under the Convention is managed by the OSPAR Commission, made up of representatives of the Governments of 15 Contracting Parties and the European Commission, representing the European Community. The work of the OSPAR Commission is guided by the ecosystem approach to an integrated management of human activities in the marine environment. Sweden has committed to the Strategy for a Joint Assessment and Monitoring Programme (JAMP). The marine environmental monitoring is found in the Co-ordinated Environmental Monitoring Programme (CEMP).

1.3.2.6 EU Shellfish Hygiene Directive

The European Union (EU) Shellfish Hygiene Directive (91/492/EEC) concerns making sure that shellfish harvesting areas are monitored to see if the shellfish are fit for human consumption. It requires member states to monitor their shellfish production areas for the presence of toxin producing phytoplankton. The directive is mainly of relevance in areas where shellfish are harvested. At present this applies only to the coasts of the Skagerrak and the northern part of the Kattegat in Sweden. The shellfish directive was incorporated into more general directives about food safety in 2004:

- Regulation (EC) 852/2004 on the hygiene of foodstuffs
- Regulation (EC) 853/2004 laying down specific hygiene rules for food of animal origin
- Regulation (EC) 854/2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption

The Swedish National Food Adminstration (Livsmedelsverket) has implemented these EU-directives in Swedish regulations in Föreskrifter om livsmedelshygien LIFSFS 2005:20 (§31-34).

1.3.2.7 EU Shellfish Waters Directive

The European Community (EC) Shellfish Waters Directive (79/923/EEC) aims to protect shellfish populations. It sets water quality standards in areas where shellfish grow and reproduce. The directive is mainly of relevance in areas where shellfish are harvested. At present this applies only to the coasts of the Skagerrak and the northern Kattegat in Sweden, i.e. in the area administered by the County Administration Board of Västra Götaland. The following Swedish documents govern the requirements for monitoring:

- SFS 2001:554. *Förordning om miljökvalitetsnormer för fisk- och musselvatten*.
- NFS 2002:6. *Naturvårdsverkets förteckning över fiskevatten som ska skyddas enligt förordningen (2001:554) om miljökvalitetsnormer för fisk- och musselvatten*.
- Länsstyrelsen Västra Götaland (2003). Länsstyrelsens förteckning över musselvatten som ska skyddas enligt förordningen (2001:554) om miljökvalitetsnormer för fisk och musselvatten. 14 FS 2002:474. Västra Götalands läns författningssamling.

1.3.2.8 IMO Ballast water convention

The International Maritime Organisation is the United Nations specialized agency responsible for improving safety and preventing pollution from ships. Sweden has ratified the International Convention for the Control and Management of Ships' Ballast Water and Sediments. This includes commitments regarding research and monitoring. Article 6; Scientific and Technical Research and Monitoring calls for parties individually or jointly to promote and facilitate scientific and technical research on ballast water management; and monitor the effects of ballast water management in waters under their jurisdiction.

1.4 The Swedish marine monitoring programme of the pelagic environment

1.4.1 Introduction

Marine environmental monitoring in Sweden is carried out in a national programme governed by the Swedish Environmental Protection Agency and in several regional programmes. The regional programmes are co-ordinated by the recently formed water authorities in Sweden. Water quality associations and other regional organisations are responsible for the work that is carried out by several partners. The regional monitoring is not described further in this report but suggestions about how to use automated techniques is put forward in the following chapters.

1.4.2 Ship based monitoring

In Sweden the national pelagic monitoring for plankton, nutrients, oxygen, salinity and temperature is performed at fixed stations (see map, fig. 2). The programme is carried out by SMHI, and the Swedish Institute for the Marine Environment (Havsmiljöinstitutet) with the nodes (Marine Research Centers) at the universities of Stockholm and Umeå. Sampling is generally 12 times per year but sampling occasions are not evenly distributed over the year. Four stations are termed intensive sampling stations and sampling is performed c. 24 times per year. In addition winter cruises with R/V Argos cover the Baltic and the Kattegat-Skagerrak for estimation of the winter nutrient pool at a higher spatial resolution. In autumn a high resolution oxygen mapping cruise is carried out. During fish monitoring cruises performed by the Swedish Board of Fisheries additional sampling of e.g. oxygen is performed. Using a FerryBox system on R/V Argos, salinity, temperature and chlorophyll a fluorescence are measured underway during all expeditions.

1.4.3 Buoys

SMHI operates three surface buoys to measure wave parameters (see, map, fig. 2 and fig. 32). These also include sensors for water temperature at the surface. In addition two systems that also include in air meteorological sensors and sensors

Table 1. Summary of the advantages and disatvantages of the sampling platforms discussed in this report.

	Temporal resolution	Horisontal resolution	Vertical resolution	Amount of detail
FerryBox systems	+++	++++	+	+++
Remote sensing	++	++++	+	+
Stationary platforms	++++	+	+ to +++	+ to ++
Research vessels	+	++to +++	++++	++++

for salinity and temperature at several depths are in operation (illustration in fig. 34). The focus of the systems is physical parameters such as salinity, temperature, wind, air pressure and waves. Also current measurements using ADCP have been carried out. Phytoplankton biomass is measured as chlorophyll a fluorescence at 2 m depth.

1.4 Why use automated systems in marine monitoring?

One of the major problems with traditional research vessel based monitoring is that cost prohibits sampling at a spatial and temporal resolution relevant to natural variability. An example is that an algal bloom often has duration of a few weeks while sampling is only monthly. High frequent chlorophyll a measurements give better estimates of annual production resulting in better estimates of fish production/ecosystem carrying capacity. Also patchiness of phytoplankton occurrence due to physical processes make sampling at fixed points problematic. The processes in surface waters are in general fast while processed in deep water are assumed to be slower. However, episodic event, e.g. short periods of hypoxia, have been shown to occur also in deep water (e.g. Tengberg & Hall, 2004). The extreme conditions during episodic events may influence the environmental status for a long time. Examples of vertical and horizontal patchiness are found in Figs 3-5 and 9-11. Examples of short term temporal variations are presented in Figs 6-11. A summary of the advantages and disadvantages with the major measurement platforms is presented in table 1. This is elaborated upon in other chapters in this report. Zhang & Bellingham (2008) investigated the design of an optimal coastal observing systems mainly from a physical oceanographic modelling point of view. The proposals in this report aim to include needs for environmental monitoring as well as needs for physical and biogeochemical modelling. Observations using buoys and Ferrybox systems are useful also for validation of satellite observations.

1.5 By-products from automated environmental monitoring

With the incorporation of automated techniques in long term environmental monitoring results can be made available in near real time (i.e. within one hour after measurement). This makes several by-products possible. These are very valuable for the society. Here follows some examples:

- Energy efficient marine transport
  - Real time information about currents and waves makes it possibly to plan the routes and arrival times of ships in way that reduces fuel consumption substantially. The total energy savings are large.
- Warnings based on observations of the current state
  - Oil spills
  - Algal blooms
  - Hypoxia (fishermen should go elsewhere)
  - Safety for merchant, fishing and leisure vessels
- Forecasts
  - Drift of oil spills
  - When and where do algal blooms hit the beaches?
  - Harmful algal bloom effects on aquaculture
  - Hypoxia (fishermen can plan their activities)
  - Flooding
  - Safety for merchant, fishing and leisure vessels
  - Improved quality of weather forecasts

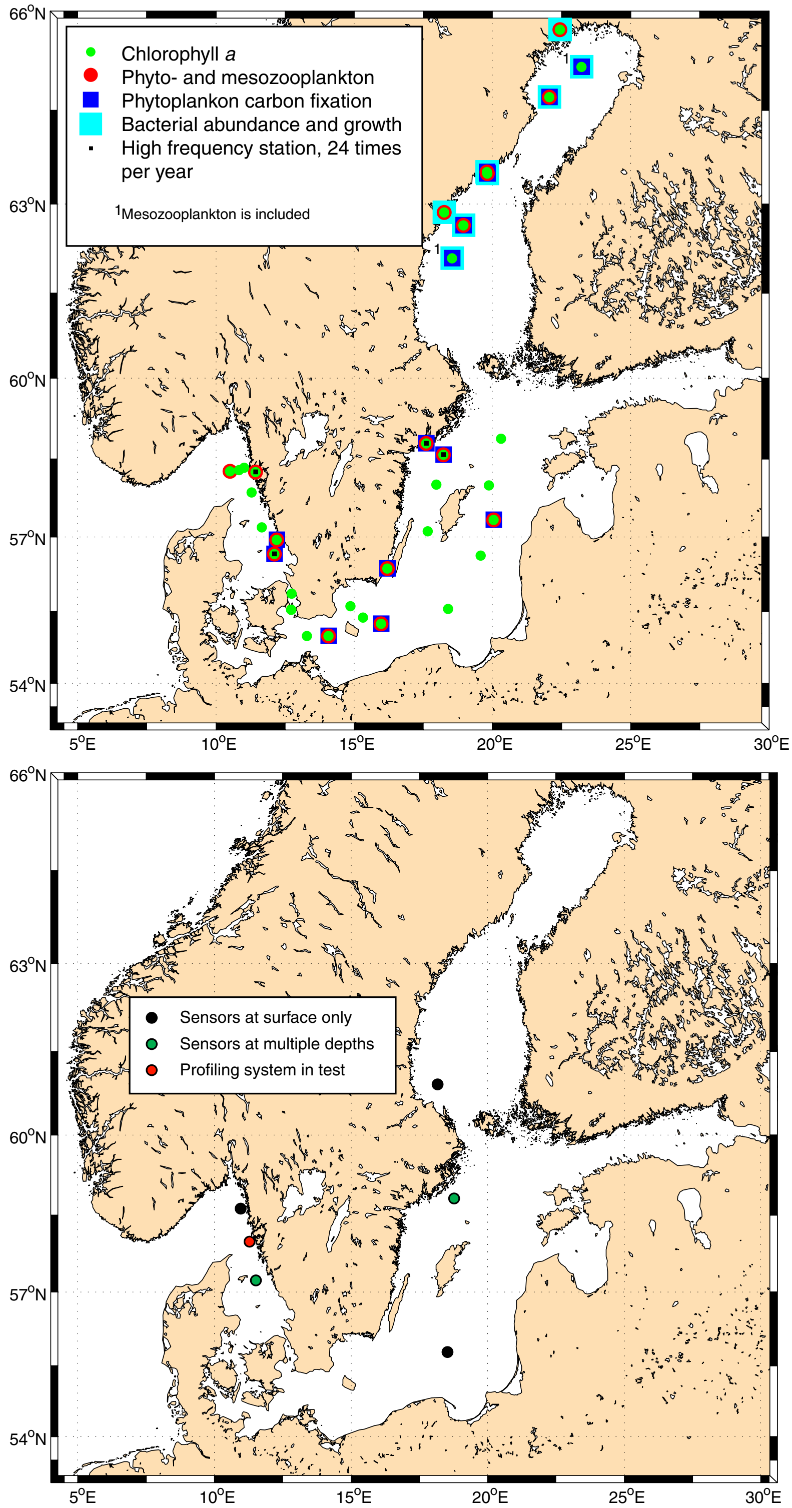


Fig. 2. Upper panel: Map showing stations for long term national monitoring for pelagic biology. Hydrographic measurements are made simultaneously. The frequency of sampling is most often 12 times per year but at a few stations 24 times per year. In addition SMHI performs a cruise in December for determination of the winter nutrient pool at a large number of stations. Sampling is made by SMHI except for station B1 in the southern part of the Archipelago of Stockholm in the Baltic Proper (Stockholm Marine Research Center) and the stations in the Bothnian Bay (Umeå Marine Research Center). Station BY31 (Landsort deep) is sampled by SMHI and the Stockholm Marine Research Center. Biological parameters other than chlorophyll *a*, oxygen and Secchi depth are sampled only at a subset of the stations (see the legend). Source www.smhi.se National Swedish Oceanographic Data Centre, version of map 20 April 2007.

Lower panel: The existing Swedish oceanographic buoys. These are described in some detail in another chapter in this publication.

Figure 3 Example of horizontal patchiness in the Baltic proper. The MERIS satellite image shows surface accumulations of cyanobacteriea on 31 July 2008. The accumulations actually visualize the large scale current pattern. An effect of the patchiness is that single station sampling in a basin is likely to give non-representative data. MERIS imge from the European Space Agency processed by SMHI.

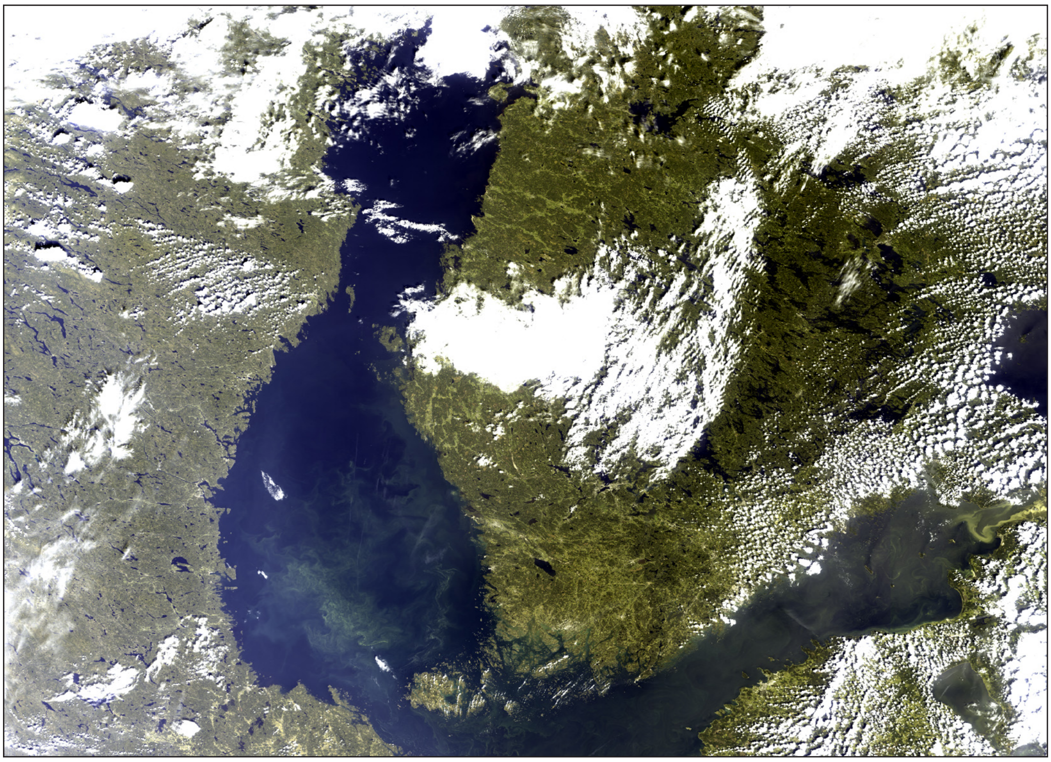


Figure 4. Example of thorizontal patchiness in the Bothnian bay and the Gulf of Finland. Surface accumulations of a bloom of cyanobacteria was observed in the Bothnian Sea and in the inner part of the Gulf of Finland on 30 July 2008. MERIS imge from the European Space Agency processed by SMHI.

Figure 5. Example of horizontal patchiness in the Skagerrak-Kattegat area. A bloom of the coccolithophorid *Emiliania huxleyi* is prominent on 31 May 2004. The surface current patterns is visulalized by the algae. The Baltic current along the Swedish coast is blocked due to physical oceanographic reasons. The signal around Denmark are probably influenced by eroded particles. MODIS images from NASA processed by SMHI.

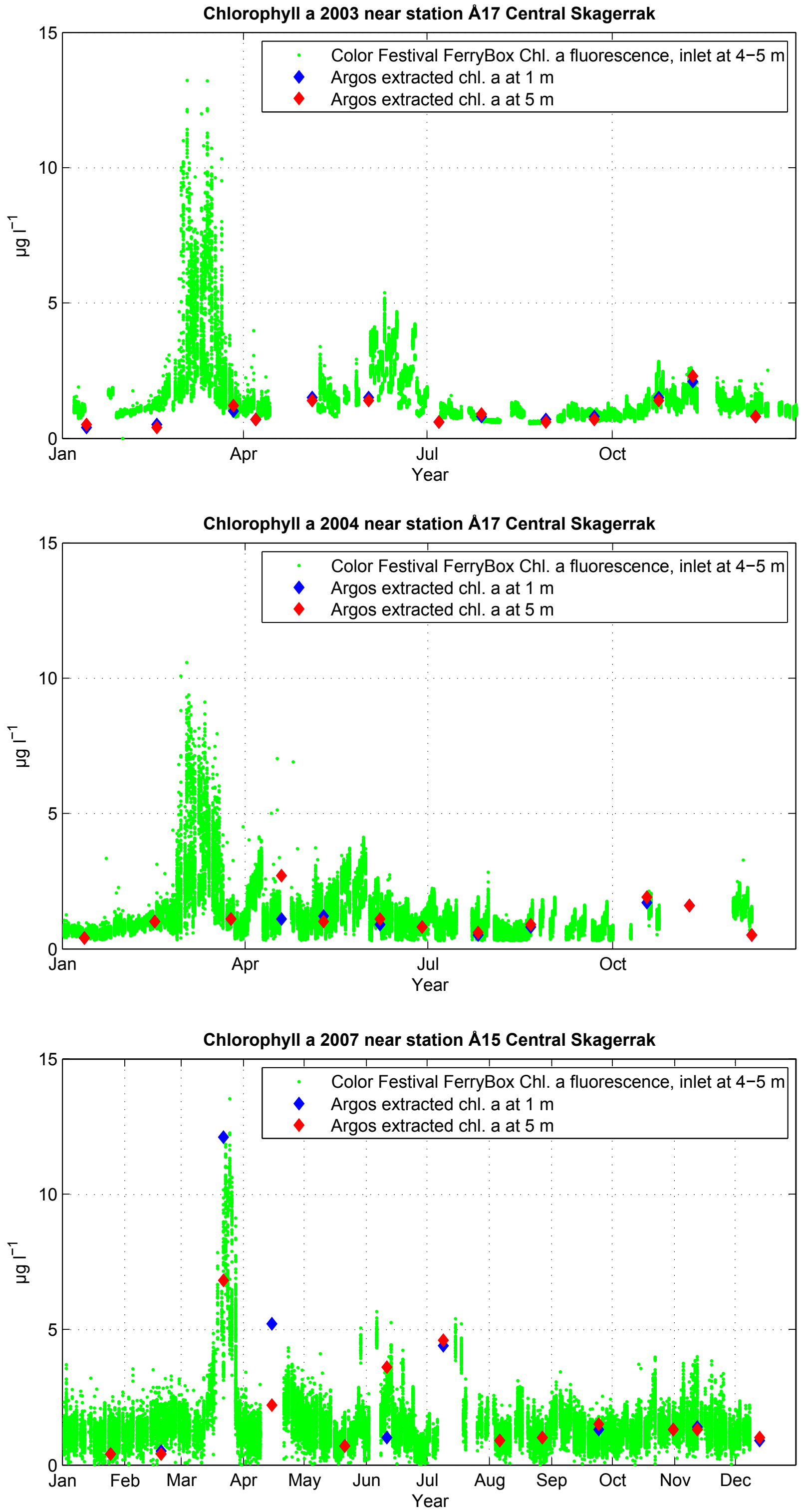


Figure 6 Example of how sampling frequency influences the results from monitoring of algal blooms in the Skagerrak. Sampling from the research vessel R/V Argos was 12 times per year while the ferry Color Festival operated the routes Oslo Hirtshals (2003-2004 data) and Oslo-Fredrikshamn (2007 data) twice per day. The spring bloom was missed by R/V Argos in 2003 and 2004 while a sampling occasions occurred during the bloom in 2007. Also the early summer blooms of coccolithophorids were more or less missed by R/V Argos sampling in 2003 and 2004.

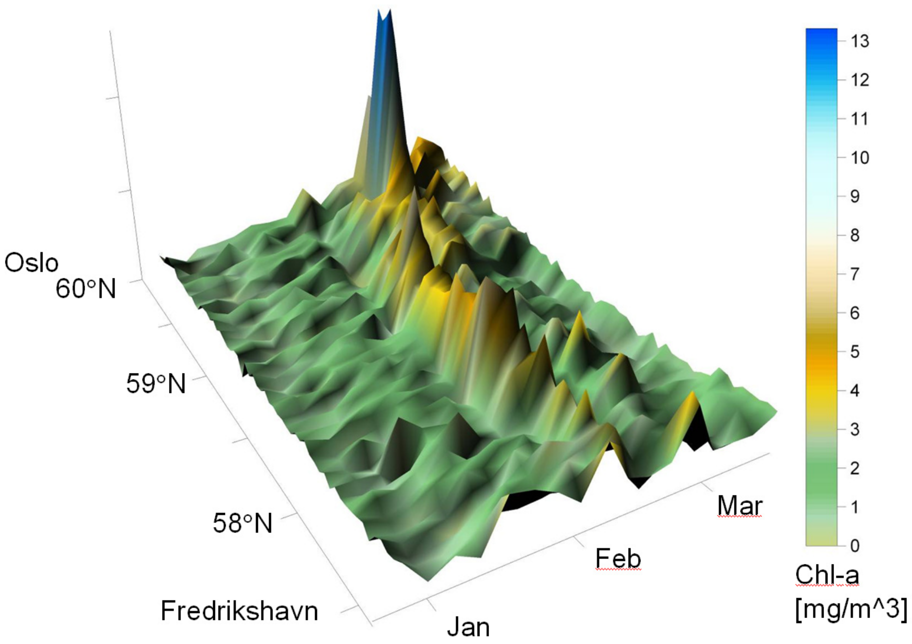


Figure 7. The spring bloom in the Skagerrak in 2007. Phytoplankton biomass was measured as chlorophyll *a* fluorescence between Oslo and Fredrikshamn. Source: NIVA.

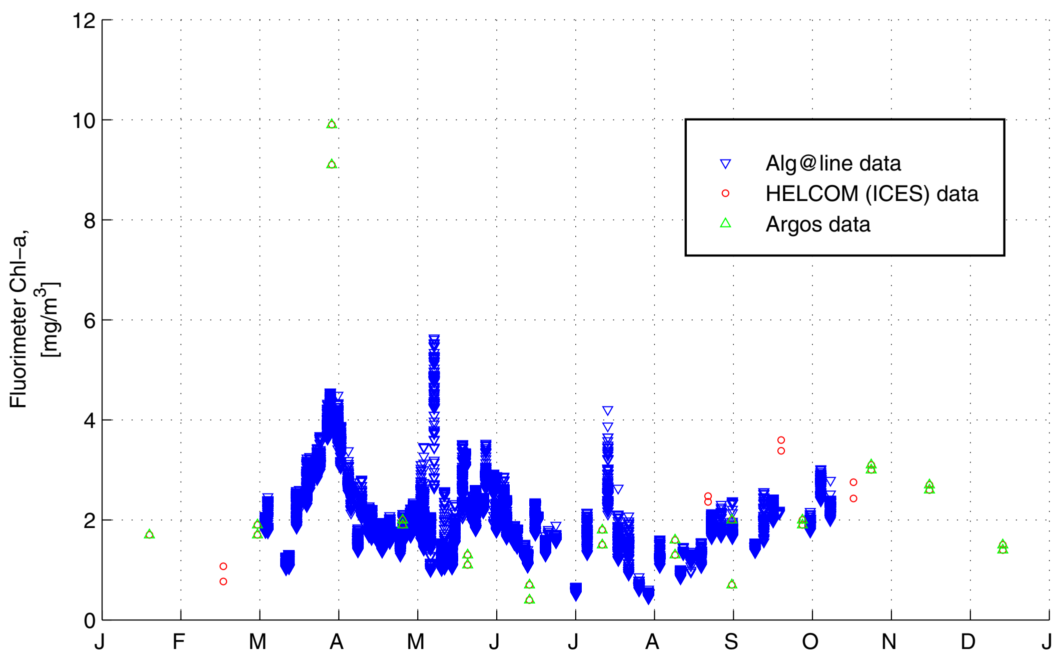


Figure 8. Example of how sampling frequency influences the results from monitoring of algal blooms at station BY1 near Bornholm in the southern Baltic in 2006. Sampling from the research vessel R/V Argos was 12 times per year while the ferry FinnMaid operated the route Helsinki-Lübeck twice per week. The spring bloom was observed by R/V Argos but blooms in May and July were at least partly missed. Data from sampling by research vessels other than R/V Argos is also shown.

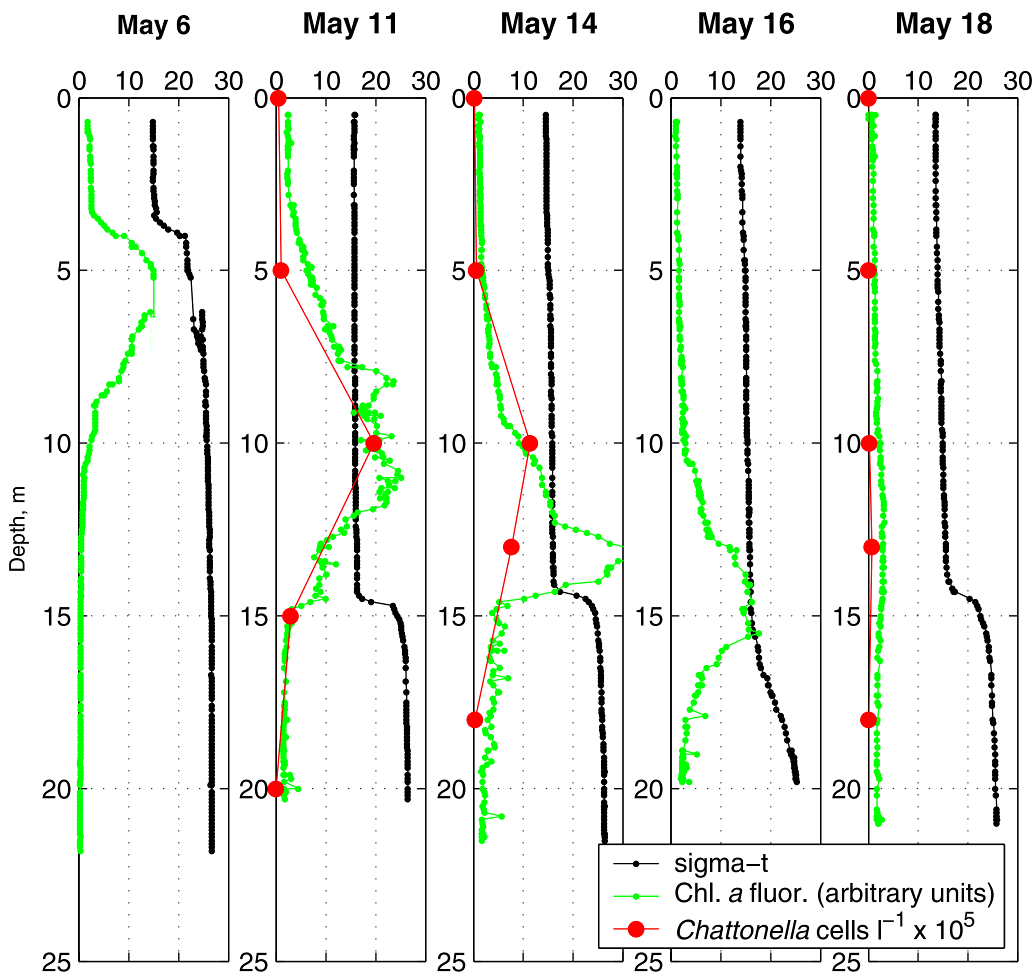


Figure 9. Example of vertical patchiness, i.e. thin layers of a Harmful Algal Bloom in the Kattegat at Valö, near Gothenburg. The example is from the first major bloom of *Chattonella* sp. (now *Psedochattonella verruculosa*) in 1998. The station is located in the Baltic current which means that water is transported northwards most of the time. The *Chattonella* cells probably have their origin in the Jutland current.

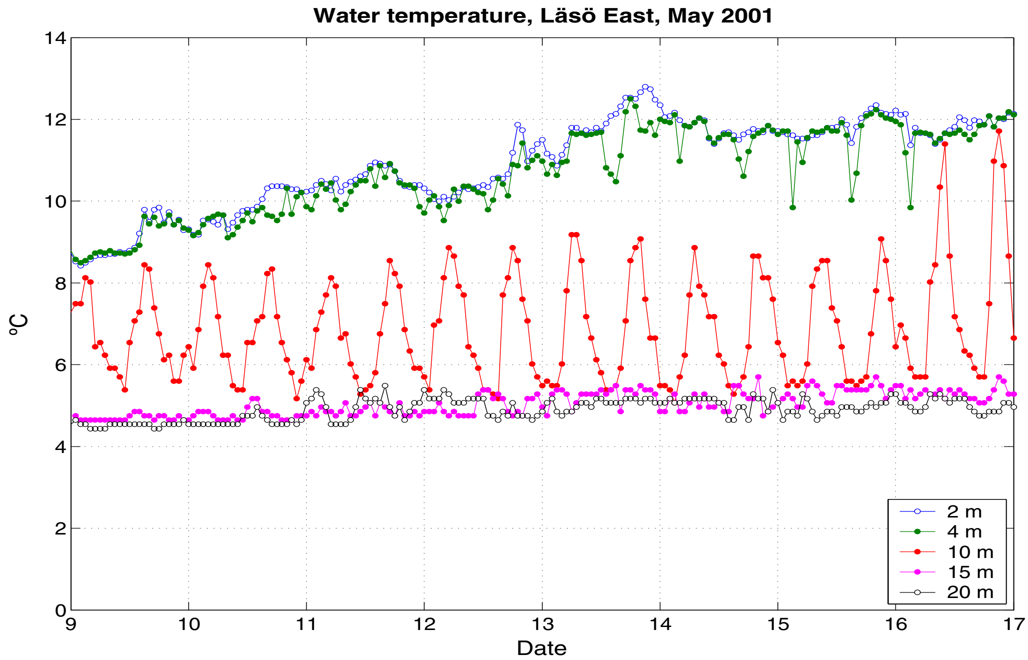


Figure 10. An example of short term variations in the Kattegat. Data is from the Läsö E. buoy. Measurements of the water temperature at several depths revealed an internal wave believed to be tidal at c. 10 m depth.

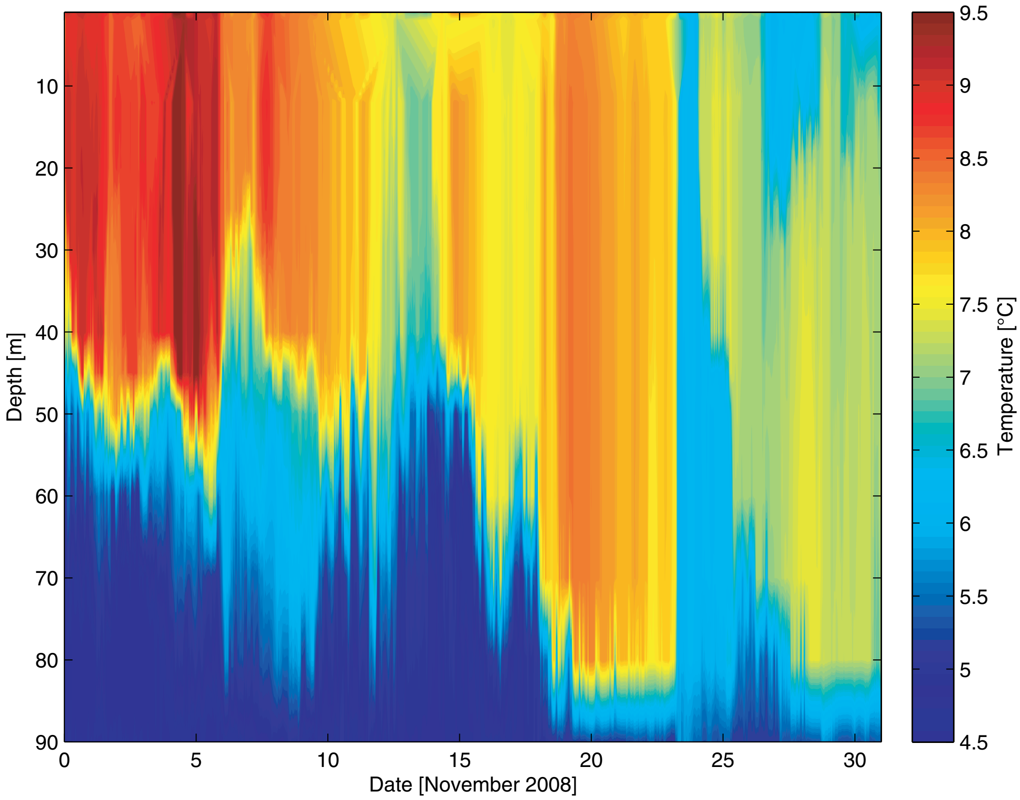


Figure 11. An example of short term temperature variations in the Baltic. Data is from the Huvudskär E. buoy. Hourly measurements of the water temperature at several depths revealed short term lowering of temperature of about two degrees at depth c. 10-50 m. The periods with lowered temperature lasted c. 24-48 hours. On 25 November a strong gale was observed with average wind speed of 19 m/s.

1.6 Web links for chapter one

Marine Strategy Framework Directive
http://ec.europa.eu/environment/water/marine/in-dex_en.htm

Water Framework Directive
http://ec.europa.eu/environment/water/water-framework/index_en.html

INSPIRE
http://inspire.jrc.ec.europa.eu/
http://www.inspire-geoportal.eu/

OSPAR
http://www.ospar.org

HELCOM
http://www.helcom.fi

IMO
http:www.imo.org

2 PRESENT STATE OF DATA ASSIMILATION IN OCEANOGRAPHIC MODELS

2.1 Introduction

There exist a number of operational and pre-operational models in several Baltic countries with the aim to either forecast or monitor the status of the Baltic Sea, Kattegat and Skagerrak. The operational models which produce daily data are to almost 100 % part of the HIROMB-BOOS co-operation, where SMHI has been the leading part since the start in the mid 80's. The implementation of coupled ecological models to the original HIROMB code has being going on during the last years and are nowadays more or less operational. Hindcasts of the last 100 years with coupled physical and ecological models have been performed and are still parts of on-going national and international projects.

No model either for the atmosphere or ocean is so perfect as to produce exact forecasts even if the initial state was exactly known. One way to improve the quality of models is to continuously make use of observations. This is called data assimilation. and has been done for the last few decades with atmospheric models. However, for the ocean, the use of observations in forecasting, reanalysis and monitoring is comparatively new. Another important use of observations is daily on-line validation of model results and validation on a seasonal scale.

Data assimilation (DA) is a method that estimates the state of the oceans from observations and background fields, taking into account additional constraints from the model. The background fields may consist of climatic data or yesterday's forecast. The DA system should be able to provide a dynamically consistent and homogeneous state of the ocean together with error statistics.

It is common to divide today's most commonly used DA methods into four classes: optimum interpolation (OI), three-dimensional variational methods (3DVAR), four-dimensional variational methods (4DVAR) and Kalman filter (KF). For operational ocean forecasts, SMHI is presently using the OI method which minimizes the mean quadratic error between the observations and background field. The 4DVAR and KF methods require an order of magnitude more CPU power compared to OI and are more complicated to implement. However, increasing computer power now makes it feasible to implement such methods.

2.2 Observations and ocean models in monitoring, climate and forecasting

Development of observations and models relies on each other in the sense that an improvement in one results in an improvement in the other. Every observation has the potential to improve the performance of the model, irrespective of if we are talking about a physical, biogeochemical, climate or a short term forecast model. The clue is to make observations as cost-effective as possible by choosing the optimum spatial and temporal resolution in relation to the resolution of the model.

A model needs an initial state and there we find the biggest demand for the number of observations. The longer the residence time in one region, the longer it takes for a model to adapt to the real state. Also the temporal and spatial correlation scales affect the amount of data needed both for initialization, validation and assimilation. An example of a model system at SMHI is presented in Fig. 12.

2.3 Data assimilation in ocean models

The existing DA methods in operational oceanographic models are still on a lower level compared with weather forecast models. The main reason is the scarcity of data at both spatial and temporal scales. DA methods for the ocean require real-time data on spatial scale comparable to the oceanic meso-scale, which is about one hundred times smaller than the atmospheric one, e.g. 5 km compared to 500 km. While there are about 700 synoptic weather stations in Sweden, the number of oceanic systems is about six, and three of these only measure at the surface. The main reason for the lack of data is that it is more expensive to make measurements in the ocean both with respect to man-power and equipment cost. On the other hand, the temporal scale is much less in the ocean especially when considering large-scale flows, i.e. above the meso-scale (larger than ~20 km). While

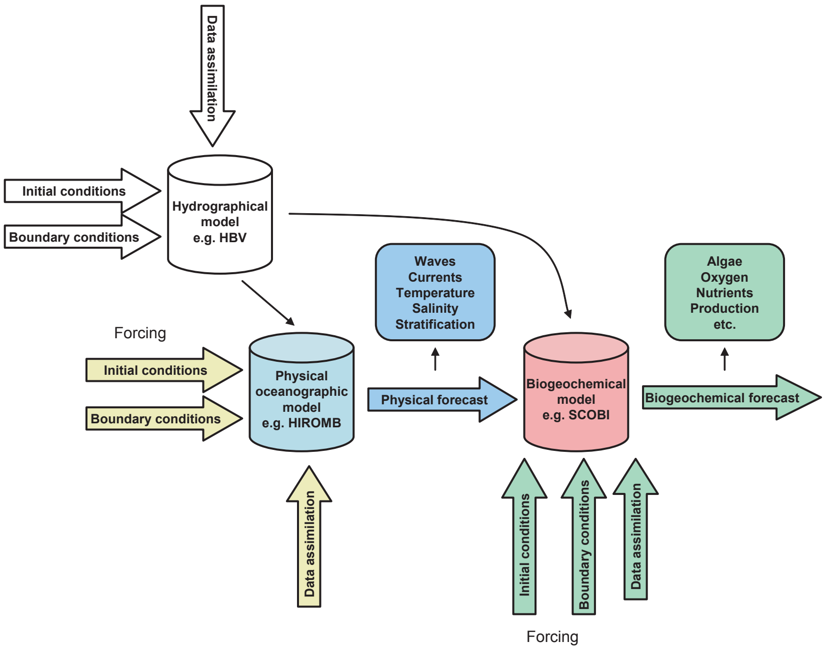


Fig. 12. An overview of one model system at SMHI. The white box represent a model for freshwater and nutrient input through rivers etc. The blue box is a three dimensional physical model describing the stratification, currents etc. The red box represent a model for the primary production, algal blooms, nutrient dynamics etc . To start a model, initial conditions from observations are required. Observations at the model boundaries are also needed. For example, most models of the Baltic have a boundary in the eastern part of the North Sea. Observations from this area are needed to successfully model the Baltic. Data assimilation is a way to push the model results towards the observed conditions.

an atmospheric model covering Sweden would require real-time data from a domain several times bigger than Sweden to produce a 24-hour forecast, a Baltic Sea model only needs real-time boundary data at the Skagerrak/North Sea boundary to produce a forecast of similar length.

2.4 Present use of data assimilation in SMHI's operational model

The assimilated variables in SMHI's operational ocean model are sea surface temperature (SST), sea ice concentration and thickness and profiles of temperature (T) and salinity (S). The SST and sea ice parameters are assimilated through daily satellite data while the T/S profiles mainly come from monthly monitoring cruises and are reported in near real time. Data assimilation in the ecological model is not yet implemented, mainly because of the sparseness of data.

Without DA the errors in both the forcing and the model itself, could make the model drift away from reality or create unrealistic structures. One example of assimilation of satellite data of SST is shown in Figure 13. The figure shows a situation with reasonably good SST observation coverage from the 1st of August 2001. One can see that the model seems to have too high a temperature and too large spatial scales in the central Baltic Proper. The assimilation decreases the temperature and imposes smaller length scales on the SST field.

An example of assimilation of a salinity profile is shown in Figure 14. As profile data from this area is only available once a month the correction may be quite large. The assimilation is able to correct for the 1 PSU difference at bottom and the 0.25 PSU difference at surface. The gradient in the halocline has also sharpened.

2.5 Optimum design of observational networks

Data assimilation is also a way to estimate key parameters and optimize the design of observing systems. SMHI participated in the EU-project ODON with the purpose of optimizing the ob-

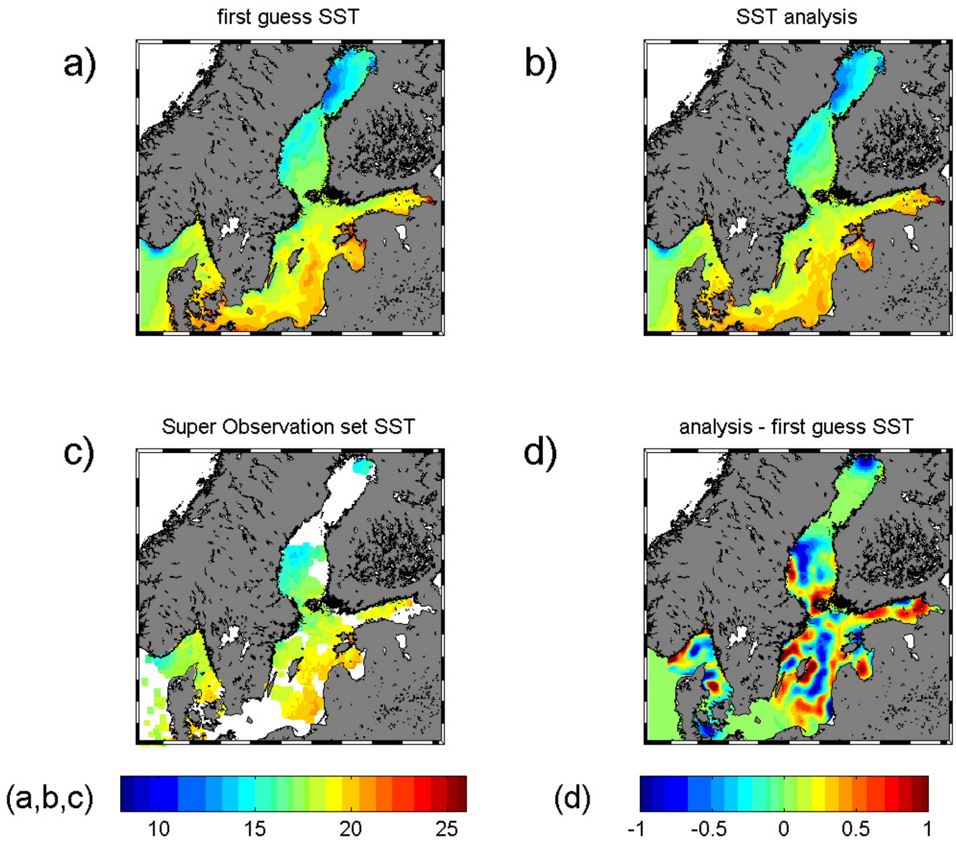


Figure 13. SST assimilation from 1/8 2001. The first guess field (a) is updated with the observations (c) using the OI method to get (b). The difference between the model's first guess and the assimilated result is seen in (d)

serving system in the North Sea and the Baltic Sea. Figure 15 shows an example from an experiment with two different observational networks for both the transition area and the Baltic Proper.

2.6 Improvements in present use of data assimilation

2.6.1 Satellite data

Satellite data (optical and SST) is only available under cloud-free conditions and thus normally covers only a small part of the Baltic Sea. The coastal area is not resolved sufficiently due to the adjacency effect (see 4.6.4). These data also need to be calibrated against regular measurements which only happens occasionally. Real-time temperature and salinity measurements in the surface layer from a FerryBox system will be able to deliver daily or weekly data for a large area including coastal regions and act as a compliment to satellite data. Therefore it would make a substantial part of the assimilation system as well as contributing to a validation of the model performances and improving the quality of the satellite products. Since the FerryBox system also measures chlorophyll a fluorescence as a proxy for the phytoplankton biomass, it could be used in connection with satellite data for assimilation into biogeochemical model.

Thus, observations from a number of FerryBox lines together with satellite will greatly improve the performance of especially the surface layer in the different kind of models. Ferrybox data are also very important for validation and developments of satellite products for e.g. chlorophyll-a.

2.6.2 Profile data from buoys and ships

The marine environment is highly dynamic, yet relatively inaccessible. Sustained observations are needed to yield meaningful information on environmental changes and their causes. Real-time profiles of physical and biochemical data are important

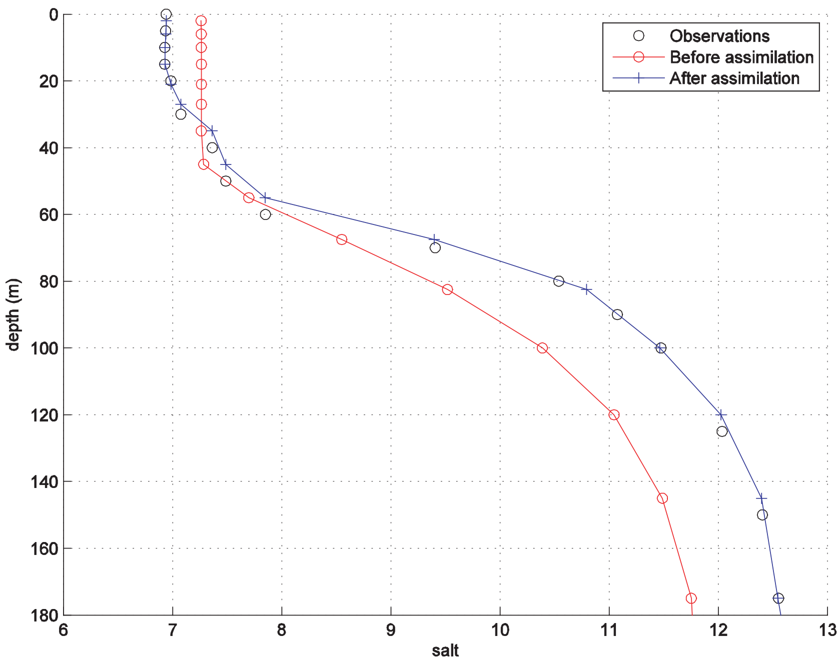


Figure 14. Assimilation of salinity at a point east of Gotland. Red and blue line is salinity before and after assimilation. Black circles are the observed values

both for daily assimilation and for validation of climate modelling.

Today, there are only two buoy stations with sensors at several depths in the Baltic Proper: in the western part of the Arcona Sea, and at Huvudskär in the north western northern Baltic Proper. Only physical parameters are measured at multiple depths. Neither station is located in an optimal position from a data assimilation viewpoint. An additional buoy with salinity and temperature sensors at multiple depths is located east of Läsö, in the Kattegat. This buoy is in a region affected by the Kattegat-Skagerrak front, where strong temperature and salinity gradients can lead to unrealistic model dynamics if data are assimilated.

A crucial process in the Baltic is the renewal of more saline and oxygen-rich water which only occurs at irregular intervals of several years. To model these episodes today's network of profile measurements is not enough and at least one buoy in each sub-basin of the Baltic is the minimum requirement.

A common draw-back of ocean models is the problem of keeping the stratification and the evolution of the depth of the mixed layer. As this problem is more or less depends on the numerics in the model, it can only be solved by access to frequent vertical profiles. An alternative would be to have a very fine vertical and horizontal resolution in the model on the cost of an increased and more or less unrealistic demand of computer power.

2.7 Justification of proposed update of existing observational network in relation to data assimilation

The proposed station network (chapters 8) will serve several requirements. One common output from all stations is the increased potential for data assimilation.

2.7.1 Coastal stations for WFD monitoring

Processes in the coastal area often have shorter scales and quite different behaviour compared to the situation in the offshore area. With regard to modelling this can most effectively be solved by coupling the larger scale offshore model to fine resolution coastal models. Coastal stations proposed in a chapter 8 are mainly supposed to fulfil the Water Framework Directive. They will contribute substantially to especially the modelling of the biochemistry in the coastal area. The quality

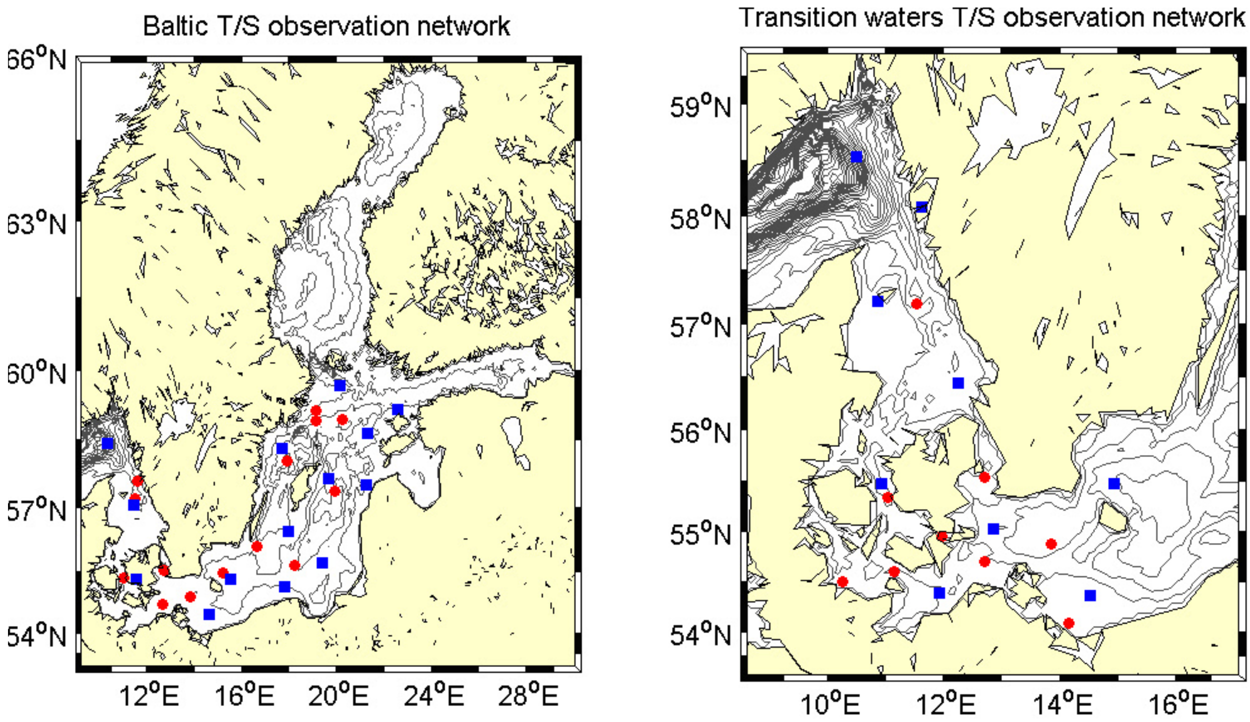


Figure 15. Baltic Sea networks (left) and transition zone networks (right) with positions of the existing (red circles) and optimal (blue squares) networks according to the results from the ODON project.

of the results of the existing model for the coastal zone (HOME-Vatten) would increase substantially if data were to be assimilated into the model. In addition frequent observations from buoys, ferries etc. would make it possible to validate the model results leading to further development of the model

2.7.2 Offshore international climate and long term ecological research stations

For climate models, it is more efficient to do measurements in areas where processes happen on longer timescales. The stations proposed in a later chapter are representative for some of the main sub-basins in the Baltic and are also chosen to be optimal in the sense of data assimilation of both physical and ecological variables. By choosing already working locations for monthly monitoring like teh Gotland deep (BY15) and the landsort deep (BY31), they take advantage of existing long time series and the possibility of calibration and maintenance of the equipment.

2.7.3 Other national stations

The other national stations proposed in chapter 8 are more selected on the basis of physics. The Bothnian Sea is undersampled compared to other regions and together with stations Finngrundet and C3, the SR5/C4 station will fill the gap also for data assimilation and a better understanding of the area. The station in the Sound (Drogden) is essential for the representation of the in/outflow from the Baltic. The temperature sensors on the already existing wave buoys at Finngrundet and Väderöbod will improve the model performance in areas with relatively high surface temperature variability.

3 AUTOMATED OBSERVATION SYSTEMS IN MARINE PELAGIC MONITORING AND RESEARCH

3.1 Introduction

Automated observation systems have been used for a long time in oceanography, e.g. for sea level measurements. Recent developments include new sensors and platforms as well as new ways to control bio fouling. In Figs 16-20 the major types of systems are illustrated. New communication systems that enable data delivery in near real time, i.e. within one hour after measurements, makes it possible to present and interpret data while an event is ongoing. Mitigation then becomes feasible, e.g. for harmful algal blooms affecting fish farms. In additon, it makes data assimilation into models possible in near real time.

3.2 Automated underwater vehicles – AUV's

There are mainly two types of AUV's, gliders and propeller driven AUV's (Fig. 16 A). Both are essentially unmanned miniature submarines with sensors for e.g chlorophyll a fluorescence, salinity and temperature. The underwater gliders somewhat resemble aeroplane gliders (sailplanes) in the sense that they glide through the water without a propeller. Buoyancy control makes it possible for a glider to operate for over a week while collecting data during the travel through the water in an undulating way. Intermittent visits to the surface are for fixing the position using GPS and sending data. AUV's are currently being tested for their usefulness in environmental monitoring. The Norwegian Institute for Marine Research has acquired one glider. AUV's are not treated further in this report.

3.2 Drifting profilers

Free drifting instrument platforms (Fig. 16 B) that has are capable of regulating their vertical position through buoyancy control are used in the oceans for determining e.g. salinity and temperature profiles. Data is transmitted using satellites. Argo is a global array of 3,000 free-drifting profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean. SMHI has plans to test floats that also contain chlorophyll a fluorescence sensors in the Baltic.

3.3 Towed instrument carriers

Already in the 1930's the Continuous Plankton Recorder was constructed. It is a fish like device (Figs. 17 and 22) being towed behind merchant ships. Plankton collect on a net and are analysed by microscope. Also the colour of the net is recorded since this is an indication of the phytoplankton biomass. The CPR is towed at a fixed depth. The long term records of plankton data from the CPR has been very valuable for observing changes in the structure of the plankton community in connection with climate change etc. Most CPR's are operated by the Sir Alistair Hardy Foundation for Ocean Science (SAHFOS) but at least two systems have been tested in the Baltic (FIMR and IMWM). The routes in the North Atlantic are shown in Fig. 34. Two routes go to Gothenburg but no sampling is performed in the Swedish parts of the Skagerrak and the Kattegat today. Sampling stops around Hanstholm. The method is mainly useful for robust species and underestimates fragile and small organisms. The CPR can be fitted with a CTD and a fluorometer. CTD data is at present not transferred in real time but could be made available quickly after the recovery of the CPR. This means that the data logging unit needs to be transported to an oceanographic laboratory for analysis of data.

Other more advanced towed instrument carriers have been developed and are used from research vessels. These are often undulating producing data from the upper c. 50-200 m part of the water column. New sensors and real time data transfer have made these instruments very useful in marine science but they require constant supervision and are considered by most not to be robust enough to be used on ferries and other merchant vessels.

3.4 FerryBox-systems

Measurement systems (table 2 and Figs. 23-28) on merchant vessels that have a fixed route have proven very valuable to collect high frequent data in the sea. Systems are found on ferries crossing narrow channels and on ships crossing oceans. A minimal

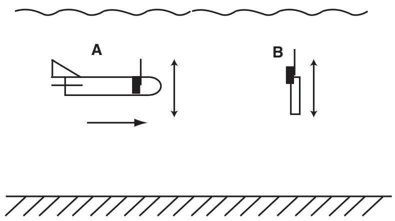


Figure 16. A. Autonomous underwater vehicles (AUV´s) move horisontally and vertically. B Drifting profiler. The black rectangles represent instrument packages.

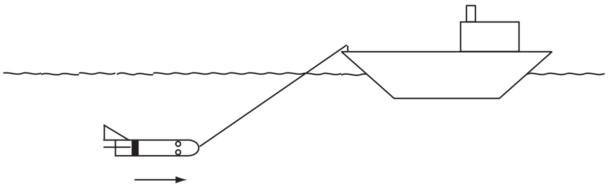


Figure 17. The Continuous Plankton Recorder (CPR) is towed behind merchant ships at a fixed depth. Zooplankton and some robust phytoplankton are collected during the tow and salinity, temperature and chlorophyll a fluorescence may be recorded also. Data is collected when the system is recovered in harbour.

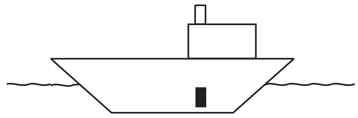


Figure 18. A. A FerryBox system usually consists of a water inlet at 3-5 m depth, sensors, water sampling equipment, pump and communication system. The black rectangle represents the whole sensor package. In addition in air sensors may be included.

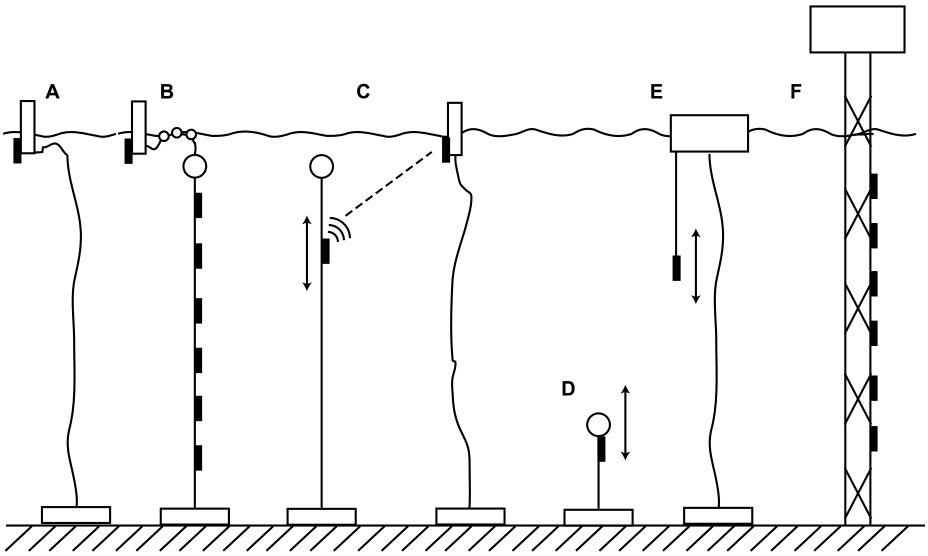


Figure 19. Various types of instrumented moorings and piles are shown in this conceptual drawing. The black rectangles represents the instrument packages. In air sensors, antennas for communication systems etc. are not included.

A Surface buoy with one set of sensors. The waverider buoys measuring waves and temperature at Väderöbod, Finngrundet and in the Southern Baltic are examples of this type.

B. Sensors along a taught wire plus sensors on surface buoy. The buoys Läse E. (Kattegat) and Huvudskär E. (Baltic Proper) are examples of this construction.

C A profiling instrument platform is used on the Måseskär W buoy. The profiler movement is due to buoyancy control and the profiler runs along a along a wire. An instrumented surface buoy transmits data to shore.

D Two american companies offer profiling systems that are winch based.

E An italian company offers a surface buoy with sensors at the end of a wire. Movement is through an automated winch. This system will be tested in the Gulf of Finland by Estonian Scientists.

F. Instrumented piles are used e.g. in the Wadden Sea, the Belt Sea and in Chesapeake bay.

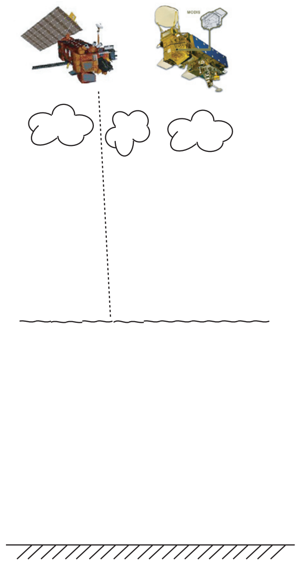


Figure 20. Satellites are used e.g. for monitoring of surface temperature, chlorophyll *a* and surface accumulations of cyanobacteria blooms during cloud free conditions. Left: ENVISAT from the European Space Agency with the MERIS sensor. Right Aqua or Terra with the MODIS sensor (NASA).

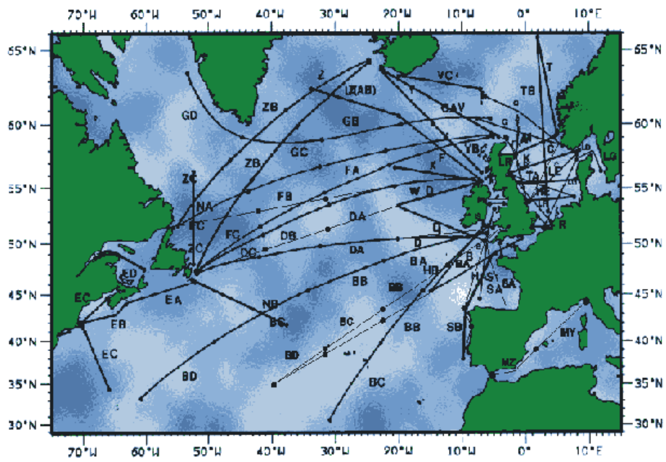


Figure 21. The map above shows the full network of continuous plankton recorder routes that have been towed over the last 75 years. Today at least two routes go to Gothenburg. Source: SAHFOS, http://www.sahfos.ac.uk

Fig. 22 The Continuous Plankton Recorder. Photo courtesy of the Sir Alistair Hardy Foundation for Ocean Science.

FerryBox-system consists of a water inlet at c. 4-5 m depth, sensors for salinity, temperature and chlorophyll a fluorescence, a pump, a GPS, a computer or datalogger and a communication system. Most often there is also a water sampling device and additional sensors both for in water parameters and in air parameters. The term FerryBox-system is used also if the system is mounted on another type of ship. The instrumented ships are sometimes called Voluntary Observation Ship (VOS) and Ship of Opportunity (SOOP).

3.4.1 Advantages with FerryBox systems

1. Covers large areas at a low cost
   a. The initial cost of a system is substantial (installation, instruments etc.) but since ship cost usually is zero the total cost is relatively low. The cost for maintaining a system, analysing water samples etc. must be accounted for when comparing with research vessel based monitoring programmes. The maintenance cost are low compared to buoys and problems with e.g. bio-fouling is also much lower than for sensors deployed in the sea for a long time
2. High frequent sampling, often daily or at a weekly interval depending on the timetable of the ship.
   a. This temporal and spatial coverage is seldom attainable using research vessels due to cost.
3. Several parameters may be measured automatically
   a. Temperature, salinity and oxygen
   b. Phytoplankton biomass (Chlorophyll-a and phycocyanin fluorescence)
   c. Particle concentration like turbidity
   d. In air sensors for e.g. irradiance and ocean colour
   e. Inorganic nutrients (not well verified in Swedish waters)
   f. CDOM (Coloured Dissolved Inorganic Matter)
4. Water sampling is possible
   a. Sampling is necessary for some parameters such as phytoplankton composition at present. This may change when optical and molecular techniques develop further. Water sampling is more or less a requirement for some other parameters such as reference samples for inorganic nutrients and also necessary for calibrations of the parameters measured using the automated sensors.
5. Data is available in near real time
6. The systems is very useful for validation of satellite data.

3.4.1 Possible problems with FerryBox systems

1. Continuity problems with ships
   o Since commercial merchant vessels are used there is always a risk that the ferry or shipping company chooses to abandon a route, replace the ship on a route and to move the existing

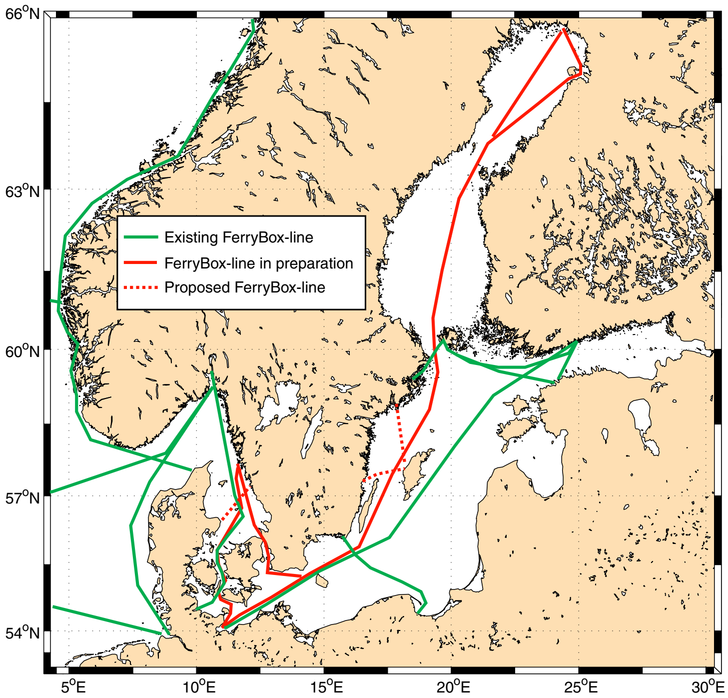


Figure 23. FerryBox routes in the Baltic Sea, the Kattegat, the Skagerrak, the eastern North Sea and the Norwegian Sea.

ship elsewhere. Commercial realities govern the choices made by the ship owners. An example of this situation is the move of the ferry Stena Nordica from the route Karlskrona-Gdynia to the Irish Sea in autumn 2008. This forces the move of a FerryBox system to another ship on the same route, but taking that into account when installing the system this is not a large problem. The FerryBox line Helsinki-Lübeck has been in operation for 14 years . There have been four different ships during this period. The termosalinograph on the coastal steamer (Hurtigruten) at the coast of Norway has been in operation since about 1930.

2. Surface water sampling only

o Water intake is usually at 4-5 m depth and whatever is happening deeper is not sampled using the FerryBox system. This is a major problem for hypoxia and also a problem for monitoring the development of subsurface harmful algal blooms.

3. Selective phytoplankton sampling

o The sampling method is different from the traditional water sampling from research vessels. The tubing used may cause artefacts regarding e.g. colonies of cyanobacteria. However, the experiences are quite good from this point of view.

4. Quality of nutrient data

o The storage of nutrient samples in a refrigerated auto sampler on the Ferry may cause concern for deterioration of samples due to biological activity. However, if storage is kept to <24 hours it is very likely that the quality will be satisfactory.

o In Norway water samples for nutrient analyses are preserved using acid by NIVA. Inter calibrations have shown that the results are comparable to the methods used by SMHI and NERI (Denmark). This makes it possible to preserve the samples automatically in the FerryBox system.

o On line nutrient analysis using automated analysis instrument on the ship is not yet fully tested. It is likely that the methodology is good but calibration of instruments and the maintenance of the system is crucial. GKSS has tested the system for several years and NIVA will start test on the Oslo-Kiel route in 2009.

5. Biofouling may cause distortion in optical sensors (fluorometers)

o Regular cleaning of optical sensors using automated or manual techniques are essential

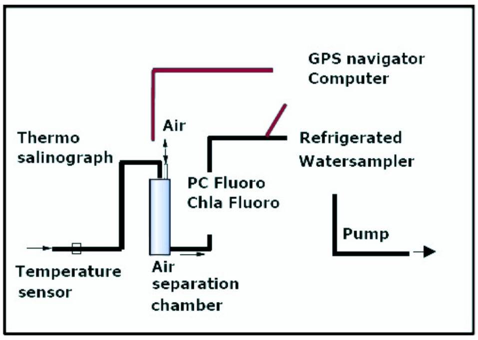


Figure 24. A diagram of the FerryBox system on the ship Finnmaid. Source: Seppo Kaitala, FIMR.

Figure 25. M/S Finnmaid, the ship that operates the route Helsinki-Lübeck (Travemünde). FIMR/SYKE has operated FerryBox systems on the route for fifteen years. Photo Christian Eckardt

Figure 26. A. TransPaper operates the route Gothenburg-Kemi-Uleåborg-Lübeck weekly. The ship is owned by TransAtlantic AB. SMHI and FIMR/SYKE are installing a FerryBox-system on the ship. Photo: Rederi AB Transatlantic.

3.4.1 Examples of successful FerryBox-systems

3.4.1.1 Helsinki-Lübeck (Travemünde)

FIMR has operated this system since 1992. In 1993 the Alg@line concept was introduced. The ships Finnjet, Finnpartner and Finnmaid has been used. The system is described in some detail elsewhere in this publication.

3.4.1.2 Tallinn – Helsinki

This route was the first with an operational FerryBox system and it is still in operation. The first trials were in 1989-1990 on the ferry Georg Ots (responsible Mati Kahru, EMI and Juha-Markku Leppänen, FIMR). The route has been operated on routine basis since 1997 with several partners from Finland and Estonia involved. The ferries used have been: Wasa Queen, Romantika; Galaxy and the Baltic Princess

3.4.1.3 Karlskrona-Gdynia

The first trials were made in 2007 on the ferry Stena Nordica by the Polish institute IMWM. SMHI installed in air sensors and a satellite communication system. In autumn 2008 the ships was moved to the Irish Sea and the FerryBox system is being transferred to another Stena ferry on the Karlskoran-Gdynia route.

3.4.1.4 Olso-Hirtshals and Oslo-Fredrikshamn

NIVA has operated a FerryBox system on the ferry Color Festival and Princesse Ragnild since 2001. The destination harbour in Denmark has been Hirtshals and Fredrikshamn. It was replaced with the Oslo-Kiel route on the ferry Color Fantasy in May 2008. The system is presented in some detail elsewhere in this publication.

3.4.1.5 Portsmouth (UK) – Santander (Spain)

This route has been operational for several years. The United Kingdom National Oceanographic Centre in Southampton is the main partner. The FerryBox-system is operated on the ferry Pride of Bilbao since 2002. Several new types of sensors under development are being tested, e.g. pH sensors and pCO2 sensors.

3.4.1.6 Cuxhaven-Harwich

This FerryBox system between Germany and England is operated by the GKSS in Germany. On line nutrient analyses has been used extensively here.

Table 3. FerryBox and some Continuous plankton Recorder routes in the Baltic Sea, the Kattegat, the Skagerrak, the eastern North Sea and the Norwegian Sea.

Route	Institute	Ship
Existing		
Baltic		
Helsinki-Lübeck	FIMR	Finnmaid
Helsinki-Mariehamn-Stockholm	FIMR	Silja Serenade
Tallinn-Helsinki	Marine Systems Institute, Tallinn University of Technology	Galaxy
Tallinn-Mariehamn-Stockholm	EMI	M/S Victoria
Karlskrona-Gdynia	IMWM	Stena Nordica
Laapenranta-Nauvo (not shown on map)	Southeast Finland Regional Environment Centre	Kristina Brahe
Kattegat-Skagerrak- Eastern North Sea		
Oslo-Kiel	NIVA	Color Fantasy
Bergen-Stavanger-Hirtshals	NIVA	Bergensfjord
Hamburg-Moss-Halden-Chatham docks-Immingham	GKSS and NIVA	Lysbris
In realisation		
Gothenburg-Uleåborg-Kemi-Lübeck-Gothenburg	SMHI and FIMR	TransPaper
Proposed		
Varberg-Grenå	SMHI	Stena ?
Oskarshamn-Visby	SMHI and University of Kalmar(?)	Destination Gotland ?
Nynäshamn-Visby	SMHI and University of Stockholm(?)	Destination Gotland ?
Nynäshamn-Ventspils	Partner in ventspils, SMHI, University of Stockholm(?)	?
Other existing systems of interest in the area (not on the map)		
Continuous Plankton Recorder		
Humber to Gothenburg via the Skaw	SAHFOS	Tor Petunia
Humber to Gothenburg	SAHFOS	Tor Ficaria
Southern Baltic near Poland	IMWM	Baltica
Baltic proper	FIMR	
FerryBox systems		
Aalborg, Denmark to Aasiat,West Greenland	Bjerknes, Bergen	Nuka Arctica
Tromsø-Svalbard	NIVA and IMR	Norbjørn
Bergen-Kirkenes (Hurtigruten)	NIVA	Vesterålen and Trollfjord
Esbjerg-Torshavn	NIVA and Marlab	Norrøna

3.4.1.7 Texel-system

On the ferry between the Dutch mainland and the island Texel a ferrybox system which includes an ADCP for current measurements is used. The FerryBox system is unusual in the way that no pump is used. The sensors are mounted on a platform that can be lowered into the water through a moon pool in the ship. The system has been in operation for several years and it is today on the second ferry.

3.4.1.8 Irish Sea system

The ferry Liverpool Viking between Birkenhead (UK) and Dublin (Northern Ireland) is part of the Coastal Observatory, Irish Sea. It has been operated by the Proudman Oceanographic Laboratory (POL) for several years.

Figure 27. FerryBox system on Color Fantasy. the ship that operates the route Oslo-Kiel. From left to right, top row: ship, below deck system and water temperature sensor at water inlet. Middle row: Pump and refrigerated water sampling system, flow through system and sensors and irradiation sensors on deck. Bottom row: water samples and automated nutrient analyser (to be included in 2009).

Figure 28. The FerryBox system on Finnmaid. the ship that operates the route Helsnki-Lübeck. Left: De-bubbler, sensors and water sampling system. Right: water inlet and pump.

3.5 Buoys and other stationary platforms

3.5.1 Overview

The last decade real time communication systems and new sensors have made instrumented moorings very useful in marine monitoring. In table 3 some examples of ocean observing systems with instrumented moorings are found and in fig. 19 examples of different types are shown. A pile is illustrated in fig. 31 while instrumented buoys are found in figs. 32-35.

3.5.2 Advantages with buoy based systems

- High temporal resolution data in near real time
- Several parameters are possible to measure:
  - Meteorological parameters
  - Physical oceanographic parameters
  - Chemical parameters, e.g. nurients
  - Biological parameters, e.g. optical properties of particles (phytoplankton)
- Useful as a sampling platform, e.g. nutrient and phytoplankton samples (e.g. Smartbuoy)
- Profiling systems provide high vertical resolution (Fig. 36)
  - necessary in stratified waters
  - makes observations of thin layers of HABs possible

3.5.3 Disadvantages with buoy based systems

Here follows some of the problems with instrumented buoys and some possible solutions.

- Risk for collision with merchant ships, trawlers etc.

  - Chose locations to avoid collisions. Place navigational buoys in positions close to measurement platform
- Technical problems

  - Regular service is required. Two systems for one location ideal
- Vandalism and thieves

  - Minor problem in offshore localities. Moorings in archipelagos may need to be observed.
- Ice

  - Make upper part of system detachable
- Long term financial commitment necessary

  - Initial investment only part of total cost
- Service of system and calibration of sensors time consuming

  - Several persons need to be involved
- Biofouling a problem with optical sensors

  - Choose sensors with bio fouling protection and a instrument platform that spends most of the time in deep water where growth is smaller compared to surface water minimizes the problem

Table 2. Examples of networks of stationary platforms.

Country	Name of system	URL
USA	Gulf of Maine Ocean Observing System (GOMOOS)	http://www.gomoos.org/
USA	Chesapeake Bay Observing System (CBOS)	http://www.cbos.org/
USA	Virginia Estuarine & Coastal Observing System	http://www2.vims.edu/vecos/default.aspx
United Kingdom	CEFAS Smartbuoy	http://www.cefas.co.uk/
United Kingdom	Coastal Observatory, Liverpool Bay	http://cobs.pol.ac.uk/
Germany	BSH MARNET	http://www.bsh.de/
Germany	GKSS Research Centre	http://www.gkss.de
France	IFREMER MAREL	http://www.ifremer.fr

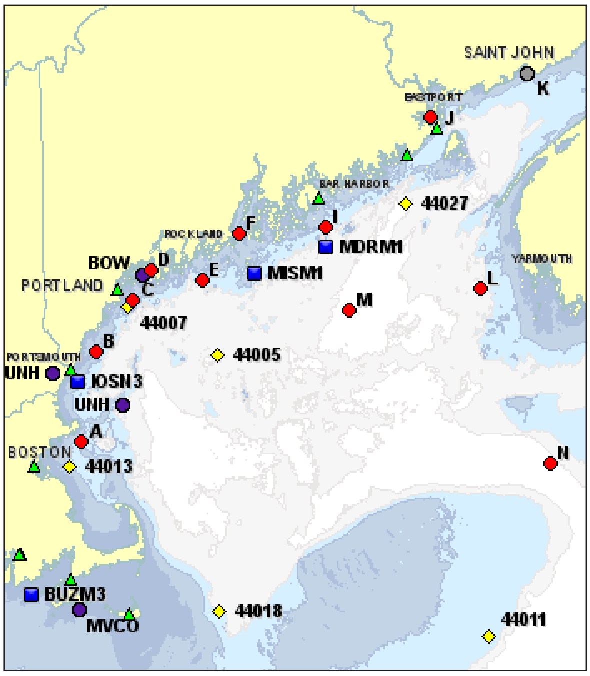


Figure 29. The GOMOOS system of instrumented moorings. GOMOOS is the Gulf of Maine Ocean Observing System in the USA. Source: http://www.gomoos.org/

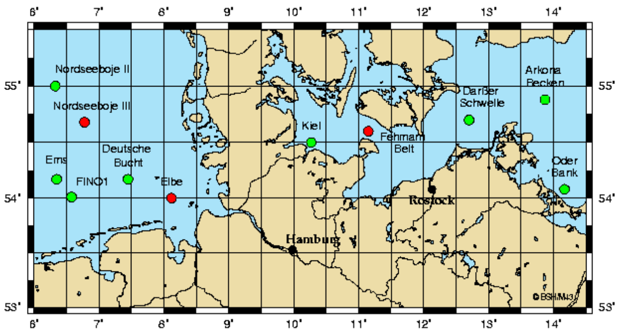


Figure 30. The MARNET network operated by the BSH (Bundesamt für Seeschiffart und Hydrografie. Source: http://www.bsh.de/en/Marine_data/Observations/MARNET_monitoring_network/index.jsp.

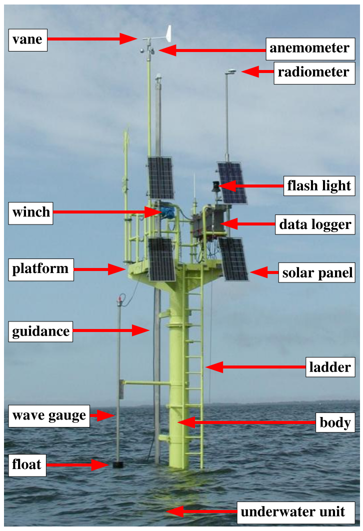


Figure 31. Wadden Sea Pile located in the Hörnum Deep, North Frisian Wadden Sea, photo Dr. Rolf Riethmüller, GKSS, Germany.

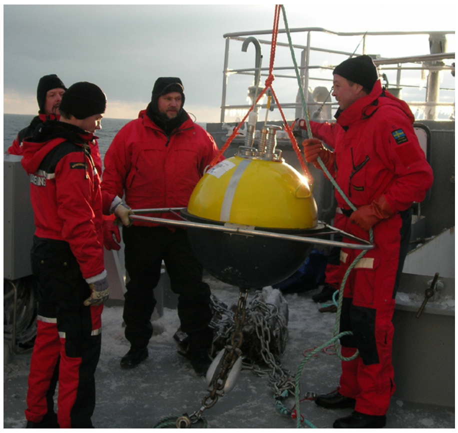


Figure 32. One of SMHI:s buoys for wave measurements. Also sea water temperature is recorded. Data are presented in near real time at www.smhi.se

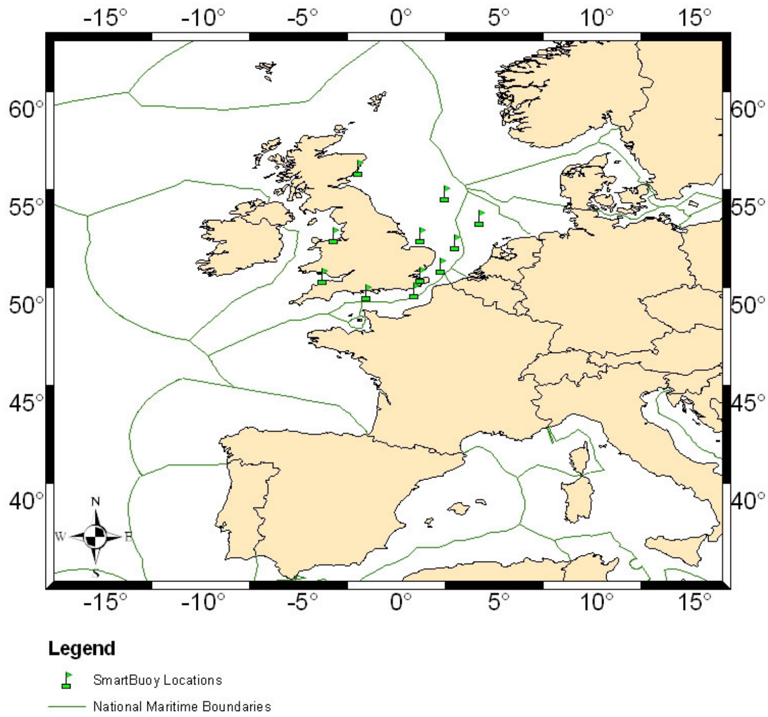


Figure 33. The SmartBuoys are operated by CEFAS in the waters surrounding the United Kingdom (map to the right). Several sensors and a water sampling device is found at c. 1 m depth. CEFAS is the Centre for Environment, Fisheries & Aquaculture Science a UK government agency.

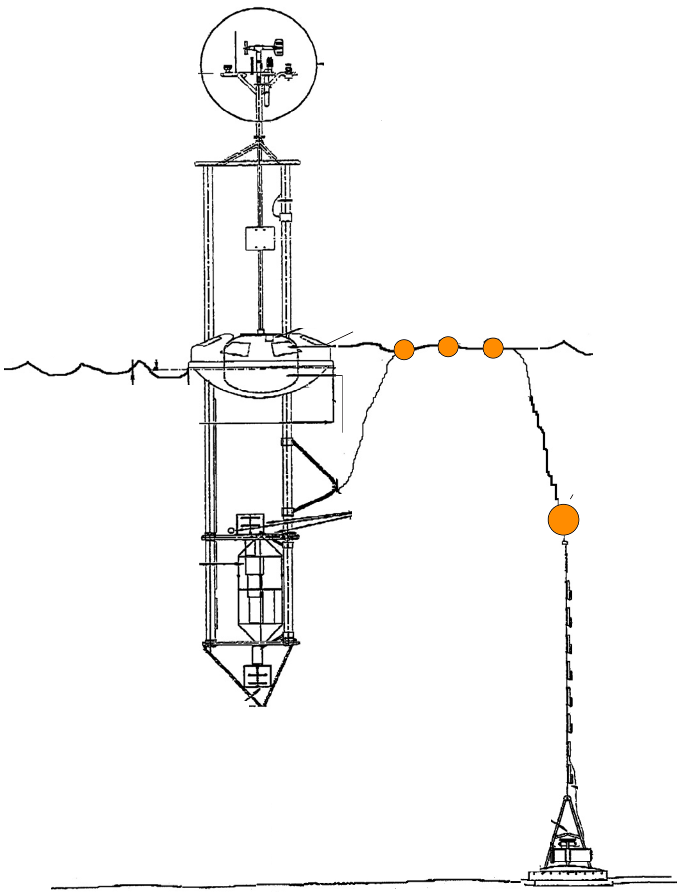


Figure 34. The SMHI buoy Läsö E. in the Kattegat. On the surface part sensors for meteorology and oceanographic sensors at 2 and 4 m depth are found. In addition wave parameters are monitored. Sensors for salinity and temperature are also found every 10 meters from the sea floor at 70 m to c. 10 m depth. An ADCP is placed on the bottom mearuring current speed and direction throughout the water column. Data are presented in near real time at www.smhi.se.

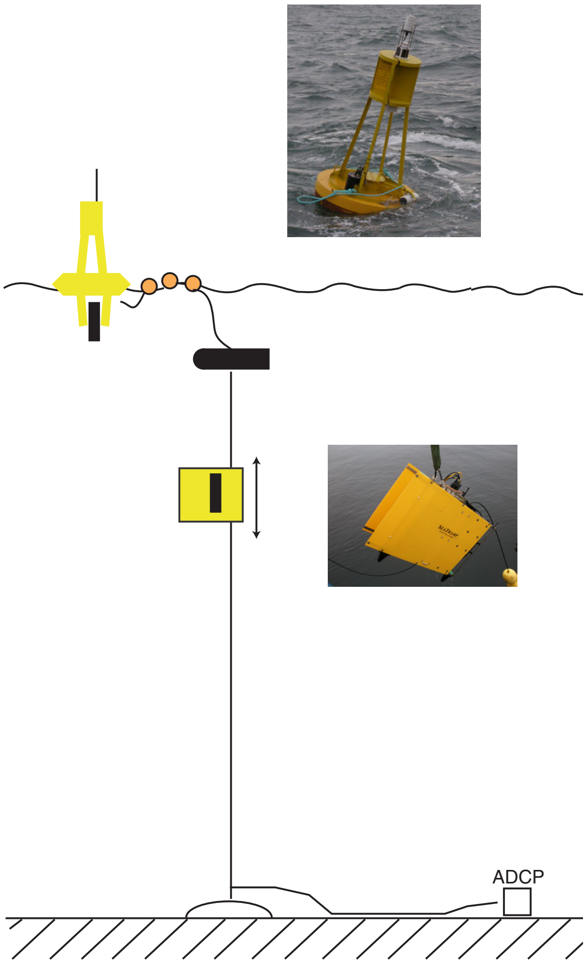


Figure 35. A. The Måseskär W buoy consists of a surface buoy with antennas for GPS and data communication and sensors in air and at 1 m. Data from the instrumented profiler has a depth resolution of c. 30 cm. The ADCP is used for wave and current measurements. A torpedo shaped float at 5 m tightens an inductive wire to the sea floor along which the profiler moves. Black rectangles represent sensors packages.

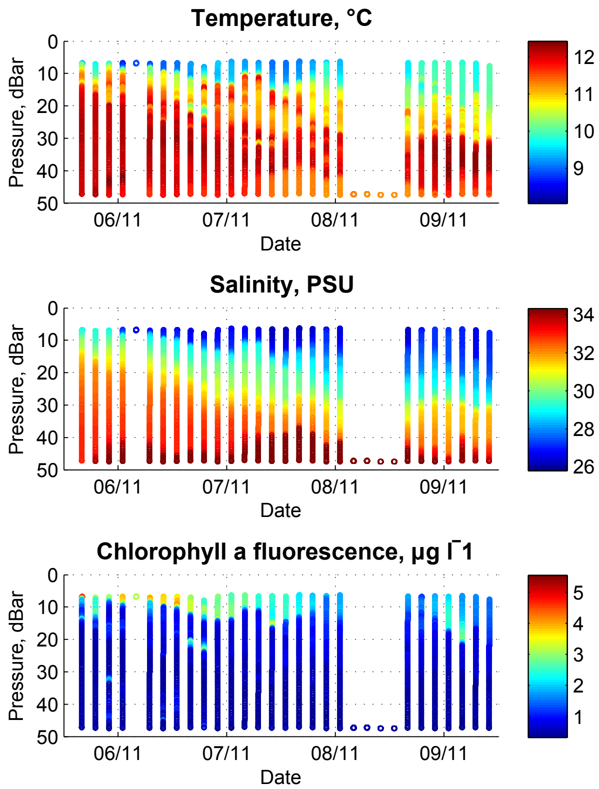


Figure 36. A. An example of data from the profiling system on the Måseskär W buoy from November 2008. The interval of profiles was 3 hours. Sampling during profiling was performed every second which translates to a vertical resolution of c. 30 cm. Also turbidity and oxygen was measured (data not shown).

3.6 Optical satellite remote sensing

3.6.1 Introduction

This subchapter focuses on remote sensing for measurements of phytoplankton and suspended matter. Also e.g. Sea Surface Temperature (SST), ice, etc. is of interest but are not covered here.

Ocean colour measurements from satellite have been used to estimate phytoplankton biomass in surface water for decades. The Coastal Zone Colour Scanner, SeaWIFS, MODIS and MERIS sensors have been used successfully for this purpose. In fig. 20 ENVISAT with MERIS and Aqua or Terra with MODIS is illustrated. In many areas clouds is a big problem for the application of remote sensing for marine monitoring. However, if composite images for a longer period (>1 week) is used the problem may be overcome. In general with the present research vessel based monitoring frequency (12- 24 times/year) the satellite data has equal or higher coverage. In the Baltic Algae Watch system, operated by SMHI, the AVHRR sensor on the polar orbiting "weather satellites" is used to detect surface accumulations of cyanobacteria in the Baltic (Hansson, 2006). This system has proven very useful for this specific purpose. It operates only during the summer months.

3.6.2 New developments

During the last year the development of satellite products like chlorophyll a and suspended material have improved. Especially after the successful launch of the European Enviromental satellite ENVISAT in 2002 the development of optical water products using the MERIS sensor has in the North Sea been successful. The MERIS sensor delivers chlorophyll-a product for both open ocean (Algal_1) and for Case II waters dominating the coast areas (Algal_2). In addition the MERIS sensors deliver a standard satellite product for suspended material (TSM). Another product called yellow substance is still under evaluation and can presently not be recommended for use.

3.6.3 Satellite products for open sea area

The Algal_2 product waters and the TSM product have in recent years been tested in the open areas of the Skagerrak and partly in the Northern Kattegat using in situ data from research vessels as well as data from the FerryBox systems operating from the Norwegian Institute for Water Research (NIVA). After the first evaluation of the chlorophyll-a product in 2003 and 2004 (Sørensen et.al. 2007) the Algal_2 product was reprocessed using data from the North Sea and Skagerrak area. The Algal_ 2 products are processed using an neural network and the satellite products was after this training better fitted to the bio-optical relation in the area. This made the Algal_ 2 products to be in relative close agreement with the in situ data (Sørensen, et.al 2008). The product TSM (Total Suspended Matter) was already from the first processing well fitted to the in situ data and work satisfactory.

In figure 38 the relation between Algal_2 product and in situ data is shown, and the similar TSM relation are shown in Figure 39. The in situ TSM is derived from turbidity measured on the FerryBox system using a relation presented in the EU-FerryBox project (Sørensen, 2006). The investigated area is between the coast of Demark and up to the mouth of the Oslofjord (59 Deg. N). In Figure 42 examples for algal_2 and TSM for a position outside Denmark compared to FerryBox data. Preliminary data show that for the open areas of Skagerrak the Algal_2 products work satisfactory in the period March to September and for TSM from February til November (Sørensen unpub.).

3.6.4 Problematic areas for optical satellite data

As stated above there are problem in the fjords and close to coast. This effect is due to the environmental effect from the surrounding land and vegetation and is called "adjacency effect". More research is ongoing to improve the algorithms for the coast and fjord areas.

Optical satellite data from the Baltic Sea has been problematic for a long time and are still a problem during bloom situations. In general the Algal_ 2 product overestimates chlorophyll-a during the

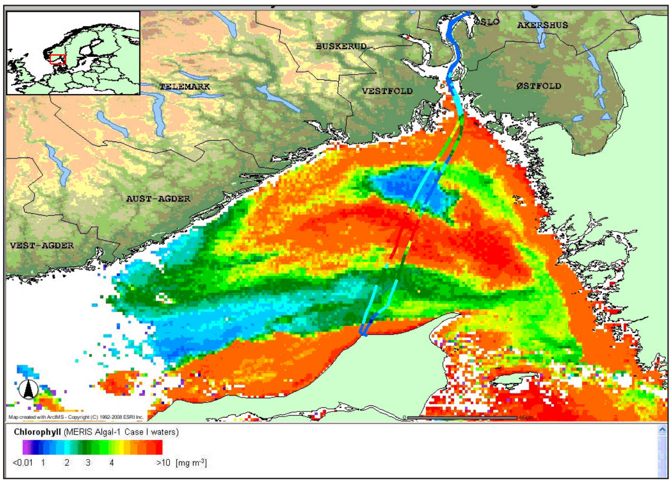


Figure 37. MERIS image of Chl-a showing a spring bloom of algae in Skagerrak in February 2008. The transect from a FerryBox system used for collecting validation data is also shown. The color coding are the same for the image and the FerryBox data.

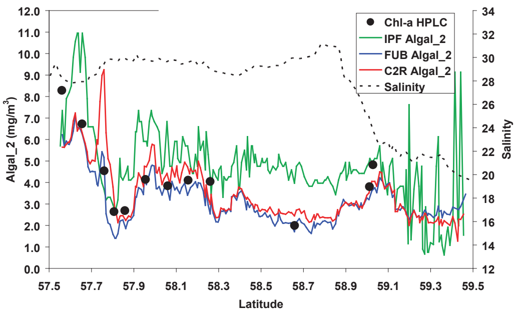


Figure 38. The transect of MERIS FUB (v1.1) Chl-a product, MERIS Case2R (v1.4 beta) Chl-a product, the standard IPF Chl-a product and Chl-a_HPLC from a transect in the Skagerrak between Denmark (57.5 N) and Norway (59.5N) on March 17. 2007. Salinity data sampled by the ferrybox system are shown for illustrating different water masses.

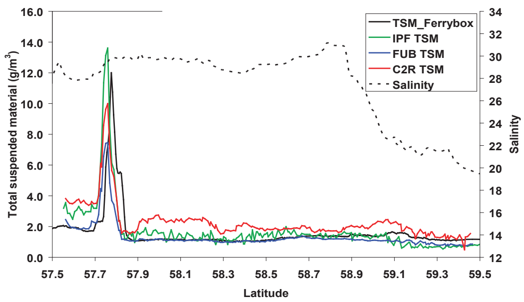


Figure 39. Transect of FerryBox and MERIS TSM for the 3 different MERIS processors; standard IPF, FUB (v1.1) and Case2R (v1.4 beta). Salinity measured by the FerryBox system is also shown.

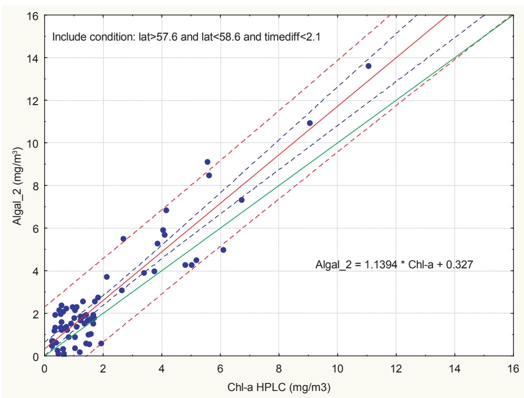


Figure 40. The relationship between standard MERIS Case 2 chlorophyll-a (algal_2) and in situ chlorophyll-a (Chl-a_HPLC) from selected FerryBox sampled data in the Skagerrak. The figure also shows the 1:1 line (green), the regression line (solid red), the 95% conf. int. for the regression (dotted blue) and 95% conf. int. for the prediction (dotted red).

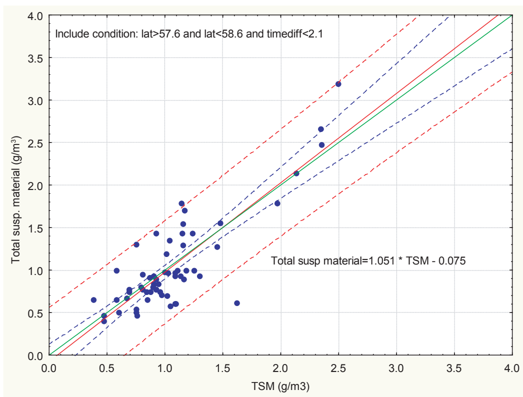


Figure 41. The relationship of MERIS Case 2 TSM product and in situ TSM from selected FerryBox data in the Skagerrak. The figure shows the 1:1 line (green), the regression line (solid red), the 95% conf. int. for the regression (dotted blue) and 95% conf. int. for the prediction (dotted red).
Source for all images on this page: Sørensen at.al 2008.

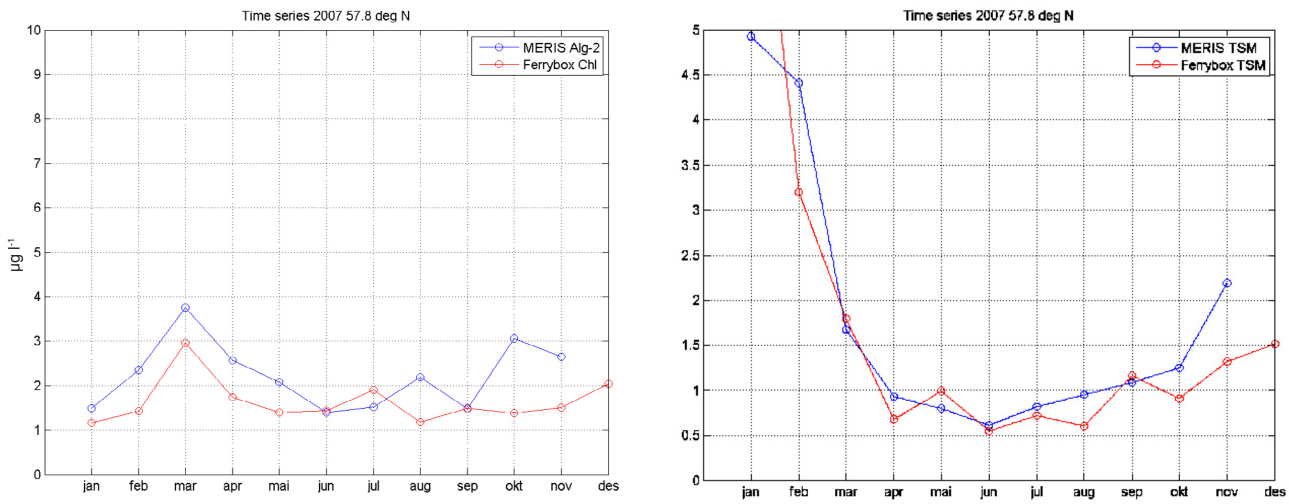


Figure 42. A comparison of data measured using the MERIS sensor on EnviSAT and measurements from the FerryBox at a site near Denmark on the route Fredrikshamn-Oslo in 2007. Left: chlorophyll a. Right: Total Suspended matter (TSM). Satellite data is from monthly averages based on composite images and the FerryBox data is based on monthly averages of chlorophyll *a* fluorescence calibrated using HPLC analyses of water samples and turbidity calibrated using standard techniques.

cyanobacteria bloom. Research is ongoing also on these issues and the establishment of the FerryBox routes in the areas will contribute to a better understanding of the problems. In connection with traditional optical research cruises information on the bio-optical relation will be established and better products can be developed. The FerryBox systems on the Color Fantasy in operation Oslo to Kiel has optical instrumentation to measure the ocean colour signal and will be used in such research. The use of sensor data and water samples from the ferries is very useful for satellite validation. In Figure 40 and 41 examples of comparisons of algal_2 and TSM products from different MERIS processors are shown.

3.6.5 Combination of techniques

The combination of the 1D information of the water constituents along a ferry line with the 2D coverage of the "same" product from the satellite (Figure 37) give the opportunity to develop a new type of product. Traditional single point measurements are important for profiling and give information of the whole water column, but do not resolve the horizontal phytoplankton patchiness in the surface water. This is well documented after studying the e.g. the transect between Denmark and Norway (Figure 37). Also the ferryline has limitations when compared to the horizontal information visible in the satellite image (Figure 37). It is obvious that use of new monitoring methods and the combination of them, in addition to the traditional methods can improve the eutrophication monitoring.

3.6 Web links for chapter three

Alg@line
www.fimr.fi

Argo floats
http://www.argo.ucsd.edu/

NIVA FerryBox
www.ferrybox.no

SAHFOS
http://www.sahfos.ac.uk/

Baltic Operational Oceanographic System
http://www.boos.org

EuroGOOS
http://www.eurogoos.org/

North West Shelf Operational Oceanographic System
http://www.noos.cc/

European Marine Ecosystem Observatory
http://www.emecogroup.org/

Global Ocean Observing System
http://www.ioc-goos.org/

Coastal observatory, Irish Sea
http://cobs.pol.ac.uk/

Norwegian Institute for Marine Research:

Thermosalinograph data from the Hurtigruten in Norway
http://data.nodc.no/termograf/

Glider
http://www.imr.no/aktiviteter/overvakning/marine_data/glider

4 PARAMETERS AND IN SITU SENSORS

4.1 General challenges

Long term deployment of sensors in the sea or in FerryBox-systems poses special problems compared to short term deployments like a CTD-cast from a research vessel. The main problem is bio-fouling. Relatively large marine organisms like barnacles and mussels are the most prominent representatives but already an, to the eye, invisible film of bacteria on optical windows influence measurements. Other instruments may be less susceptible to fouling but essentially all instrumentation deployed longer than a few days need protection from bio-fouling. Several approaches have been used to combat bio-fouling (Babin et al. 2008) and the most successful one seem to be to apply copper shutters near optical windows or copper tubing or grids at the water inlets. In FerryBox systems regular manual cleaning every week or every second week combined with automatic air pressure or fresh water cleaning of the optics has been successful.

Ring tests and intercalibrations are important issues for marine monitoring. To be able to compare data from different laboratories and data obtained using different kinds of instruments it is a necessity. The automated techniques need to be included in these tests. QUASIMEME (Quality Assurance of Information for Marine Environmental Monitoring in Europe) is an organisation that organises these kinds of tests for marine laboratories. In the USA the Alliance for Coastal Technologies tests instruments for real time systems and publishes results of intercalibrations.

4.2 Nutrient sensors

There are mainly two types of nutrient sensors available for automated marine monitoring. The most common one consists of a miniaturised wet chemistry system that is succesfully used e.g. in Chesapeake bay. The chemistry is essentially identical to the type of analyses that is used in the laboratory with an auto analyser. Nitrate, nitrite, phosphate, silicate and ammonium may be analysed in this way. Several manufacturers produce this type of analyses equipment. The analysers used for in situ deployment, e.g. on buoys, require regular maintenance as all other systems. A service interval longer than one to two months is not yet feasible in waters with strong bio fouling, e.g. the waters surrounding Sweden. Also the stability of reagents may be an issue. The use of nutrient analysers on ferries or in other relatively protected areas has been successful. Here the problem with bio fouling is relatively restricted. Regular maintenance and replacement of reagents is necessary for high quality results. This is usually carried out when the whole FerryBox is being cleaned and water samples collected e.g. once a week or every fortnight.

Another type of nutrient sensor utilizes the optical properties of nitrate to analyse nitrate concentrations. Nitrate absorbs UV-light at certain wavelengths. There are today two in situ instruments available that are based on this principle. One of them has been tested by SMHI. A preliminary conclusion is that the detection limit and accuracy is not adequate for the waters surrounding Sweden.

4.3 Phytoplankton biomass

There are at least three different approaches to determine phytoplankton biomass using automated systems. The most common one is to measure chlorophyll a fluorescence. A problem with the method is that chlorophyll a fluorescence may vary depending on the composition of phytoplankton or due to light conditions. One example is that cyanobacteria show a relatively low chl. a fluorescence per chlorophyll a unit. (Seppäla et al., 2007). Many cyanobacteria also show fluorescence from phycocyanin. Seppälä et al (2007) showed that a combination of chl. a fluorescence and phycocyanin fluorescence give a good estimate of phytoplankton biomass in the Baltic.

Irradiance influences the capacity of chlorophyll a fluorescence for phytoplankton substantially (see Figs. 43 and 44). The effect is called photoquenching and the result is that chlorophyll a fluorescence may vary of a factor of about 2-3 for the same phytoplankton community if measurements are performed in strong sunlight during daytime or in darkness. In practice the problem is smaller but it has to be accounted for when chlorophyll a fluorescence is used as a phytoplankton biomass estimate.

Another approach for determining phytoplankton biomass is the use of buoys with irradiance sensors at several depths. The extinction of light is correlated to the biomass of phytoplankton in the water. This approach has been successfully used by Cullen et al in Canada. A concern in coastal waters is that other particles and dissolved organic material will interfere since they also will cause light attenuation

A third approach is to use in situ microscopes to identify and measure individual cells or colonies of phytoplankton. This is described further in the next section.

4.4 Phytoplankton composition

Rough estimates of the composition of phytoplankton at the class level are possible using fluorescence from specific pigments for some groups. The most relevant one for Swedish waters is the fluorescence from phycocyanin from the large cyanobacteria forming blooms in the Baltic. Another candidate is phycoerythrin fluorescence from dinoflagellates belonging to the genus Dinophysis. These dinoflagellates produce diarrhetic shellfish toxins and are of concern mainly where mussels are harvested for human consumption.

A much more precise method is microscopic analyses of water samples by a skilled phytoplankton identification specialist. This has been performed routinely from samples from FerryBox systems for many years, e.g. by FIMR in the Baltic and by NIVA in the Skagerrak. It is essential that the phytoplankton is preserved as soon as possible, preferably directly on the ship. In the United Kingdom automated sampling systems are used on the Smartbuoys. The samples are collected in plastic bags pre filled with Lugol's solution. Sampling is every other day (pers. com. David Mills). CEFAS is the Centre for Environment, Fisheries & Aquaculture Science, United Kingdom.

Since microscopic analyses is time consuming and requires well trained personnel a number of approaches have been tried to develop automated methods. One is to use particle counters and flow cytometers with built in cameras. In general the human eye is still superior to the automated techniques but one approach show great promise and has actually been used successfully in situ. By combining a flow cytometer with a fast camera that takes pictures of individual phytoplankton it is possible to analyse phytoplankton samples semi automatically. A desktop system has been available for several years (Sieracki 1998) and is used by several institutes and universities around the Baltic and the Skagerrak-Kattegat. Recently a new in situ system was used successfully during a harmful algal bloom of the dinoflagellate *Dinophysis*. This system (Sosik and Olsen 2007 and Olsen and Sosik 2007) is currently being further developed.

Larger organisms, such as aggregates of the cyanobacteria in the Baltic may be identified and quantified using video technique. The distribution of cyanobacteria in the Atlantic was mapped in this way (Davis, et al. 2006).

Several automated molecular biological techniques are under development for identifying and quantifying especially harmful algae. Tests in the laboratoy have been succesful but at present the authors are of aware of only one system that have been empoyed in the sea (Greenfield et al., 2006).

4.5 Oxygen

Newly developed optode based sensors have been shown to produce reliable measurements of oxygen in sea water. These new sensors have been used both in FerryBox-systems (e.g. Southampton-Bilbao and Oslo-Kiel) and on stationary platforms. A disadvantage with these sensors is that they require a relatively long time (c. 30 sec.) before a stable reading is possible. This may be pose a problem using fast depth profiling sensor platforms but not with FerryBox systems. Profilers need to be stopped at specified depths.

4.6 pCO2, pH and alkalinity

These parameters are essential to describe the carbonate system in the oceans. The analysis techniques are not covered here but it should be noted that the requirements for accuracy and precision are very high if the data should be used in climate change monitoring since relatively small changes are important. The desired accuracy is for pH ±0,001 units, for total alkalinity ±1 μmol kg^{-1} and

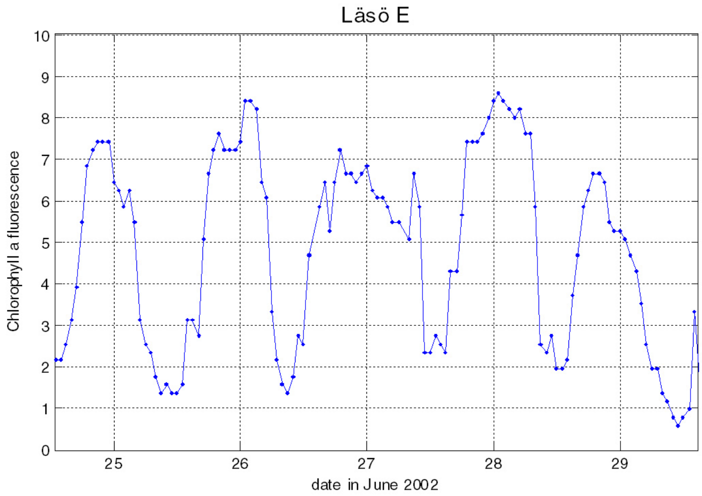


Fig. 43. An example of the pitfalls of using chlorophyll a fluorescence for estimates of phytoplankton biomass. This extreme example from the Läsö E mooring in the Kattegat shows chlorophyll a fluorescence measured every hour at 2 m depth in June 2002. Photoquenching, causing a decrease in chlorophyll a fluorescence, is evident in day time. Vertical migration of phytoplankton is not a likely explanation for the diel variation in chlorophyll a fluorescence since light attenuation data show no diel change. The recomended procedure is to use data from darkness, e.g. around midnight, only. Photoquenching effects deeper down are less pronounced and in FerryBox systems it seems to be a relatively small problem that can be accounted for if irradiance data is used. In the ferrybox systems there is also some dark adaption in the system removing some of the effect.

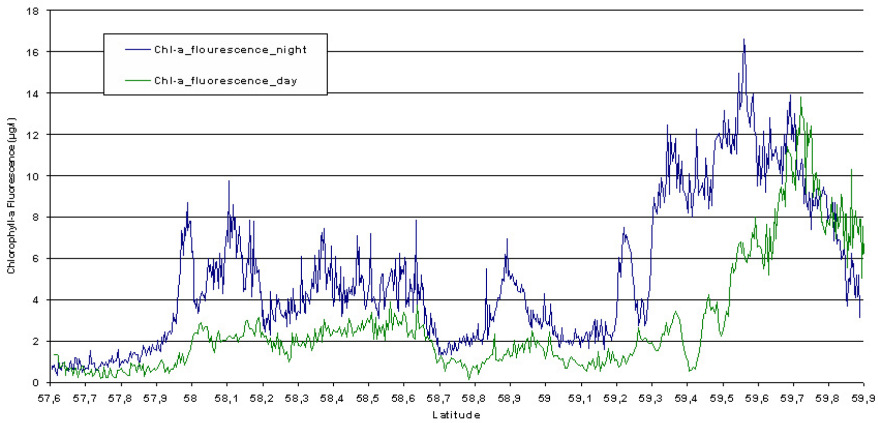


Figure 44. A. Chlorophyll a fluorescence measured using the FerryBox on Color Fantasy between Fredrikshamn and Oslo during day and night. A photo quenching effect is obvious during daytime. Data from daytime can be corrected using irradiance data (Sørensen, unpublished).

for pCO2 ±1 ppm = 1 µatm (pers. comm. Agneta Fransson, University of Gothenburg).

4.7 Turbidity

Turbidity is often measured to estimate the amount of particles in the water. The results may be used to estimate water transparency, e.g. the extinction coefficient or Secchi depth. Some phytoplankton, e.g. coccolithophorids, produce a strong turbidity signal. Most often the actual measurement is of scattering. Small bubbles may introduce scattering. Thus it is necessary to take care to avoid these bubbles when designing e.g. FerryBox flow through systems.

4.8 Attenutation and absorbance

Measuring attenuation of light in the water is a method to determine the amount and composition of particles and dissolved substances in the water. A move from single channel sensors towards spectral systems makes it possible to get some information about what particles, e.g. phytoplankton, are present. Smaller instruments often have 25 cm path length while systems with sensors at several depths results in path lengths of several meters. Attenuation is actually a combination of scattering and absorbance.

4.9 Salinity

Salinity is a fundamental property of seawater. It limits the range of marine (and freshwater) organisms, is a tracer, and its influence on density, mixing and stratification a primary reason behind the anoxic nature of the central Baltic basins. While remote sensing techniques have been tried, at the present time salinity is determined by in-situ methods or from water samples.

Salinity is reported in practical salinity units. The practical salinity scale is the current UNESCO standard, and is based on the ratio of conductivity between the sampled water and a standard solution, and as such is dimensionless. A recent IAPSO working group has presented an Absolute Salinity Scale, which would permit the reporting of salinity in terms of mass of salt per unit mass of water (Millero et al, 2008; Feistel, 2008).

In situ salinity is measured either by conductivity or induction sensors. The HELCOM Combine Programme requires a salinity accuracy of 0.05, which is should be easily attainable with a regularly calibrated, properly operated CTD system. Because biofouling is a problem however, regular maintenance is necessary to ensure that underway systems routinely meet this standard. Data quality issues may also arise with the presence of bubbles in the sample.

4.10 Temperature

Temperature is a fundamental property that influences density (and particularly summer stratification) as well as controlling various biological processes, such as the ability of cyanobacteria to fix atmospheric nitrogen. As temperature affects the calibration of many oceanographic sensors (e.g. salinity, oxygen, pressure), thermistors are usually combined with other sensors. Not all built-in sensors have the combination of fast time response and absolute accuracy needed to describe (for example) internal waves or gravity currents, while a mismatch in the time response of temperature and conductivity data can lead to artefacts such as salinity spikes. Biofouling may lead to a change in the thermal properties of a thermometer (its thermal mass) and thus its time response characteristics, which can in turn affect data quality. Thermometers in FerryBox systems and on e.g. buoys should be validated against reference thermometers regularly.

4.11 CDOM and humic substances

Coloured dissolved organic matter (CDOM) is a mixture of several substances including humic substances. There are several resaons to measure CDOM. Only two will be discussed here. Since CDOM is a semiconservative parameter it can be used to differentiate water types. Another reason is that the chlorophyll a signal that sensors such as MERIS and MODIS on satellites detect is heavily influenced bv CDOM concentrations. This is one reason why chlorophyll a estimates using satellites in the Baltic is problematic since CDOM concentrations in the Baltic are quite different from other seas. By measuring CDOM using automated techniques (fluorescence) in FerryBox systems the quality of surface phytoplankton biomass estimates using satellites will be much improved. Reference water samples are analysed for CDOM content in the laboratory.

4.12 Oil products

Automated sensors for content of oil products in sea water are available in the form of fluorescence detectors. One of these are evaluated in the Skagerrak-kattegat by NIVA at present.

4.13 Web links for chapter four

Quality Assurance of Information for Marine Environmental Monitoring in Europe
http://quasimeme.ipsum35.emmaportal.nl/

Alliance for coastal technologies (USA)
http://www.act-us.info/evaluation_reports.php

5 EVALUATION OF DATA QUALITY FROM FERRYBOX-SYSTEMS IN THE BALTIC SEA AND THE SKAGERRAK-KATTEGAT

5.1 Comparison of research vessel data from R/V Argos and FerryBox data from FerryBox systems in the Skagerrak and the Kattegat

5.1.1 NIVA FerryBox Data Availability

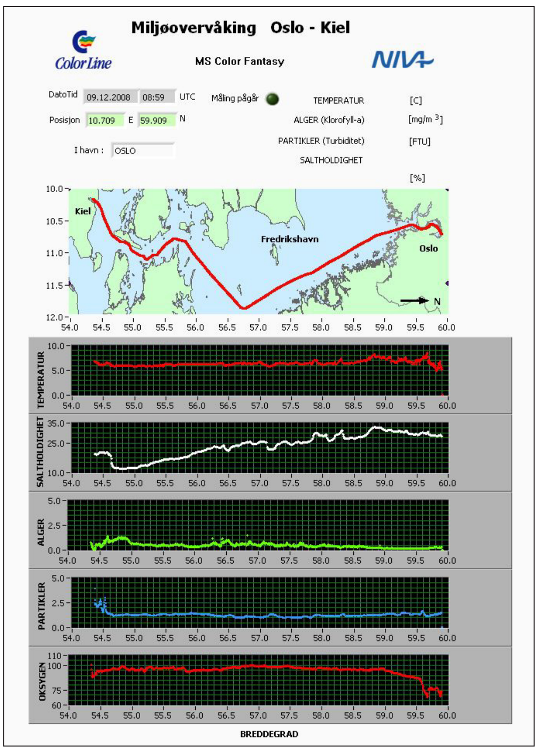
Data was available from the ferry Color Festival from the route Oslo-Hirsthals for years 2003 and 2004. For the year 2007 data was available for the same ship but for a slightly different route, Oslo-Fredrikshamn. For 2008 data were available from May onwards for the route Oslo-Kiel from the ferry Color Fantasy. A map showing the routes of the ferries in the Skagerrak-Kattegat is shown in fig. 45 as well as an example of data presentation in near real time. Figures 46-47 show data the full data sets from the FerryBox. The reliablity of the system is high. Figures 47-54 contrast selected data from the ferrybox with data from sampling with R/V Argos. Nutrient data from FerryBox sampling was not available for evaluation in the present report.

5.1.2 Physical parameters

A very good agreement between FerryBox data and R/V Argos data was observed for temperature. For salinity the correlation was a little lower. This can be explained by the high spatial and temporal variability in surface salinity where even a few hours time differences will influence the comparison.

5.1.3 Biological parameters

Chlorophyll a fluorescence from the FerryBox-showed a relativeley good agreement with the chlorophyll a measured in the water samples from R/V Argos at stations in the Kattegat and the Skagerrak (Figs 48-54). It was evident that the monthly sampling frequency for the R/V Argos did not capture the variablility in chlorophyll a concentration.
The spring blooms in 2003 and 2004 were obvious in the FerryBox data sets while they were not observed in the data sets from R/V Argos. This is also the case for the blooms of coccolithophorids in late spring in 2003 and 2004. These blooms show up in both the chlorophyll a fluorescence data and in turbidity data. In 2007 sampling from R/V Argos occured during the spring bloom.



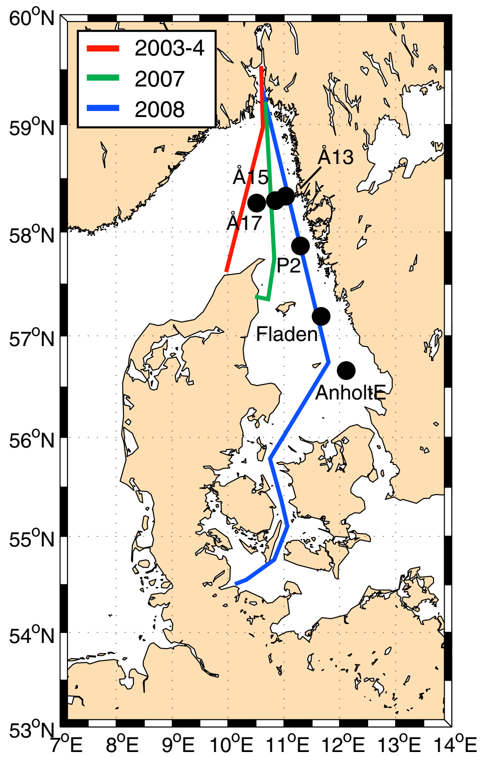


Figure 45. Left. An example of near real time presentation of data from the FerryBox on Color Fantasy on the route Oslo-Kiel. Right Map showing the stations where data comparison between water sample data from R/V Argos and ferrybox data is made. Data from 2003, 2004 and 2007 are from the ferry Color Festival and data from 2008 is from Color Fantasy.

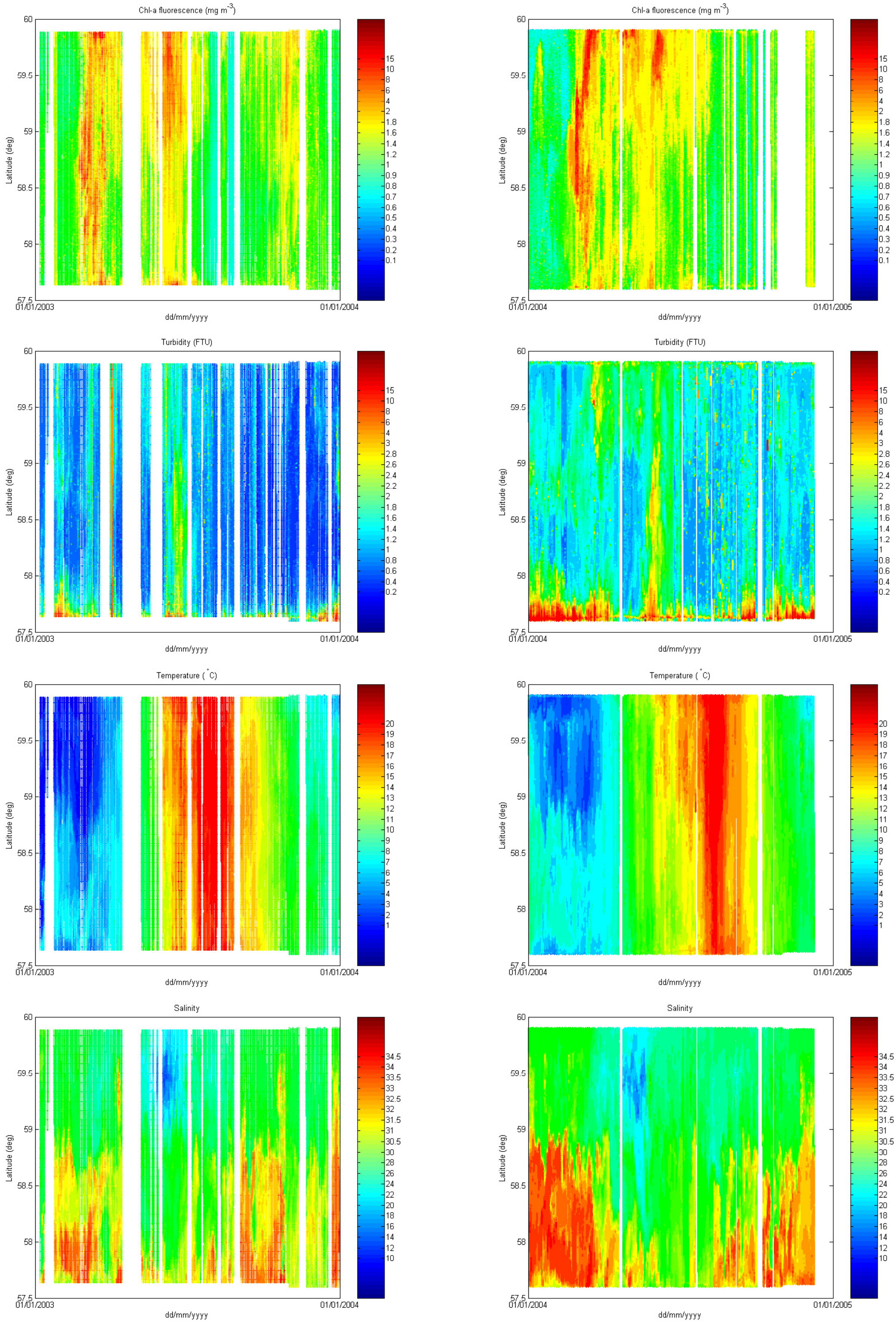
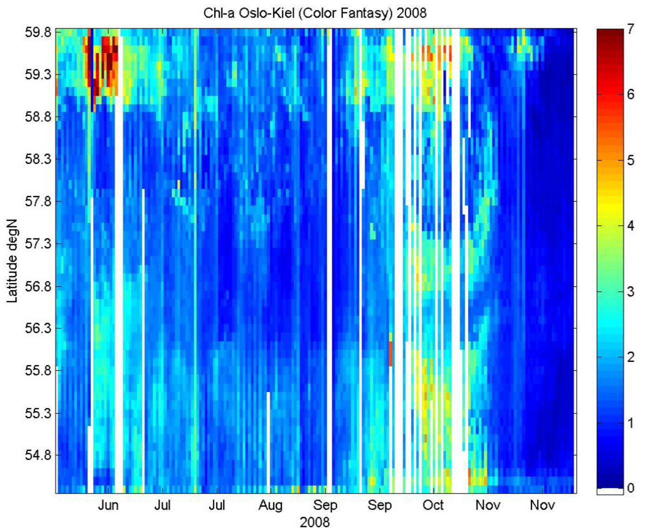
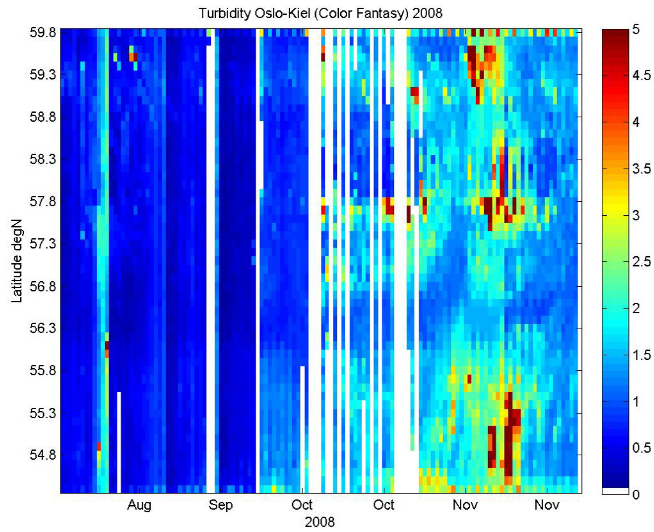
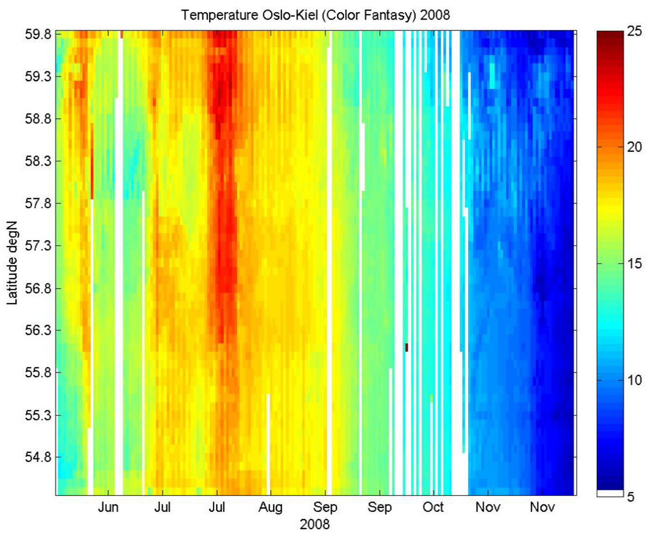
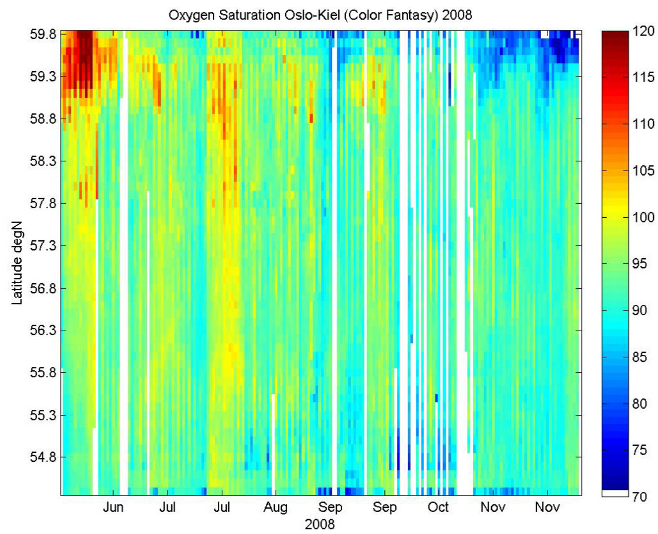


Figure 46. Temporal and spatial variability in surface Skagerrak water along transect Olso-Hirtshals. Results are from the NIVA FerryBox on Color Festival 2003 (left) and 2004 (right). From top: Phytoplankton biomass measured as chlorophyll *a* fluorescence, water transparency measured as turbidity, temperature and salinity. The spring bloom is evident in chl. a. fluorescence signal and the bloom of coccolithophorids in 2004 is also seen in the turbidity signal.









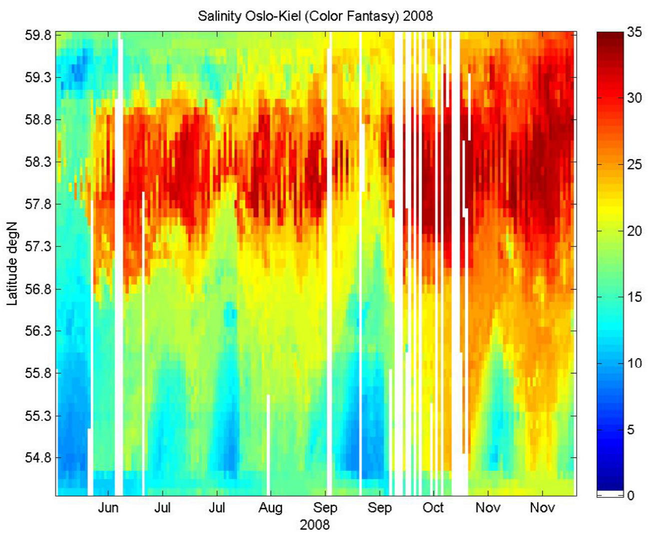


Figure 47. Temporal and spatial variability in surface Kattegat and Skagerrak water along transect Olso-Kiel in 2008. The system was operational from late May. The turbidity data is not finally calibrated.

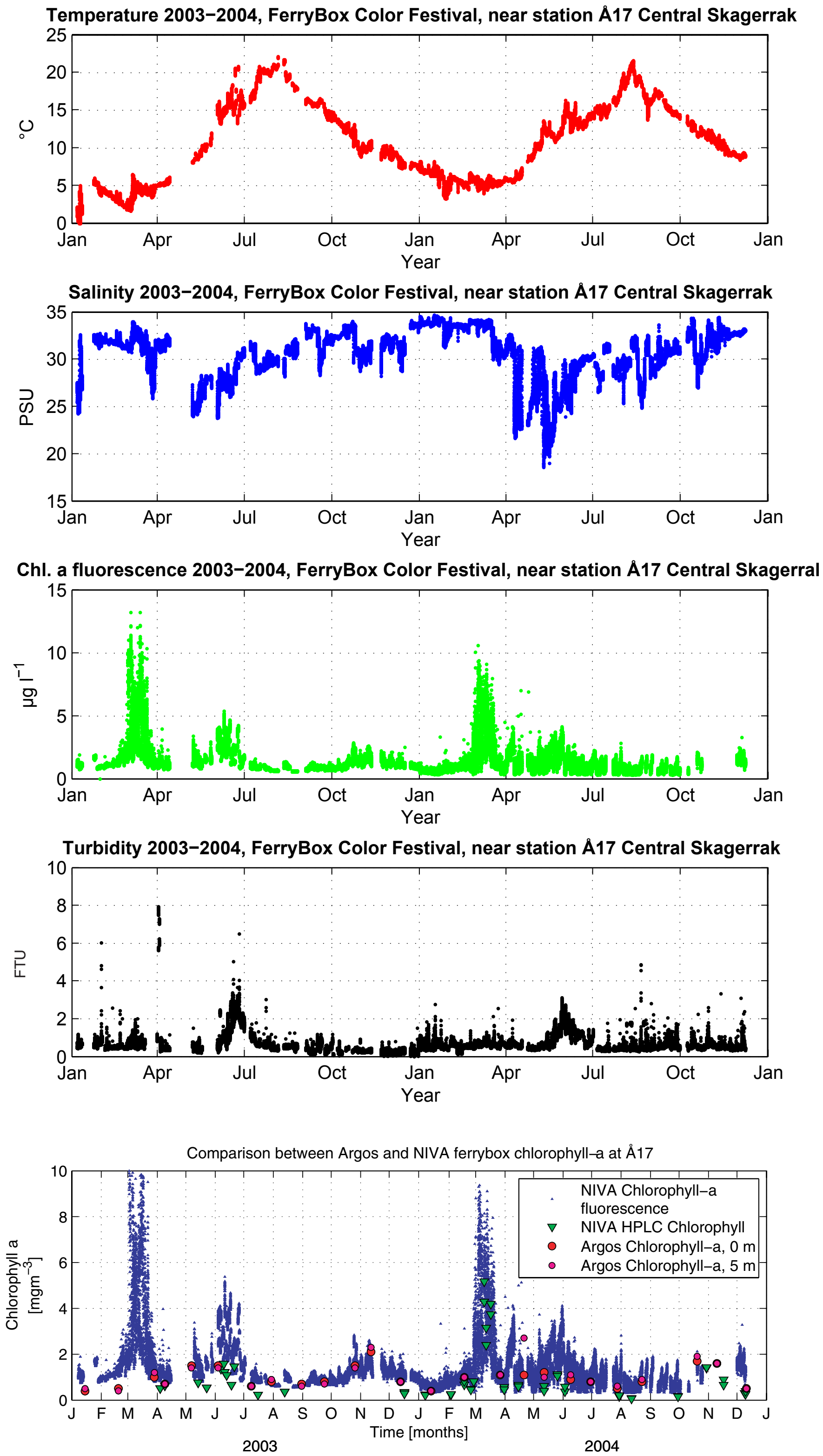


Figure 48. Data from station Å17 in the Skagerrak. In the bottom graph a comparison between chl. a fluorescence from FerryBox-system, water sampling from FerryBox and water sampling from R/V Argios is made. Chl. a from waters samples was analysed after filtering and extraction. Chl. a was analysed using HPLC from the FerryBox samples and using a fluorometric method for the samples from R/V Argos.

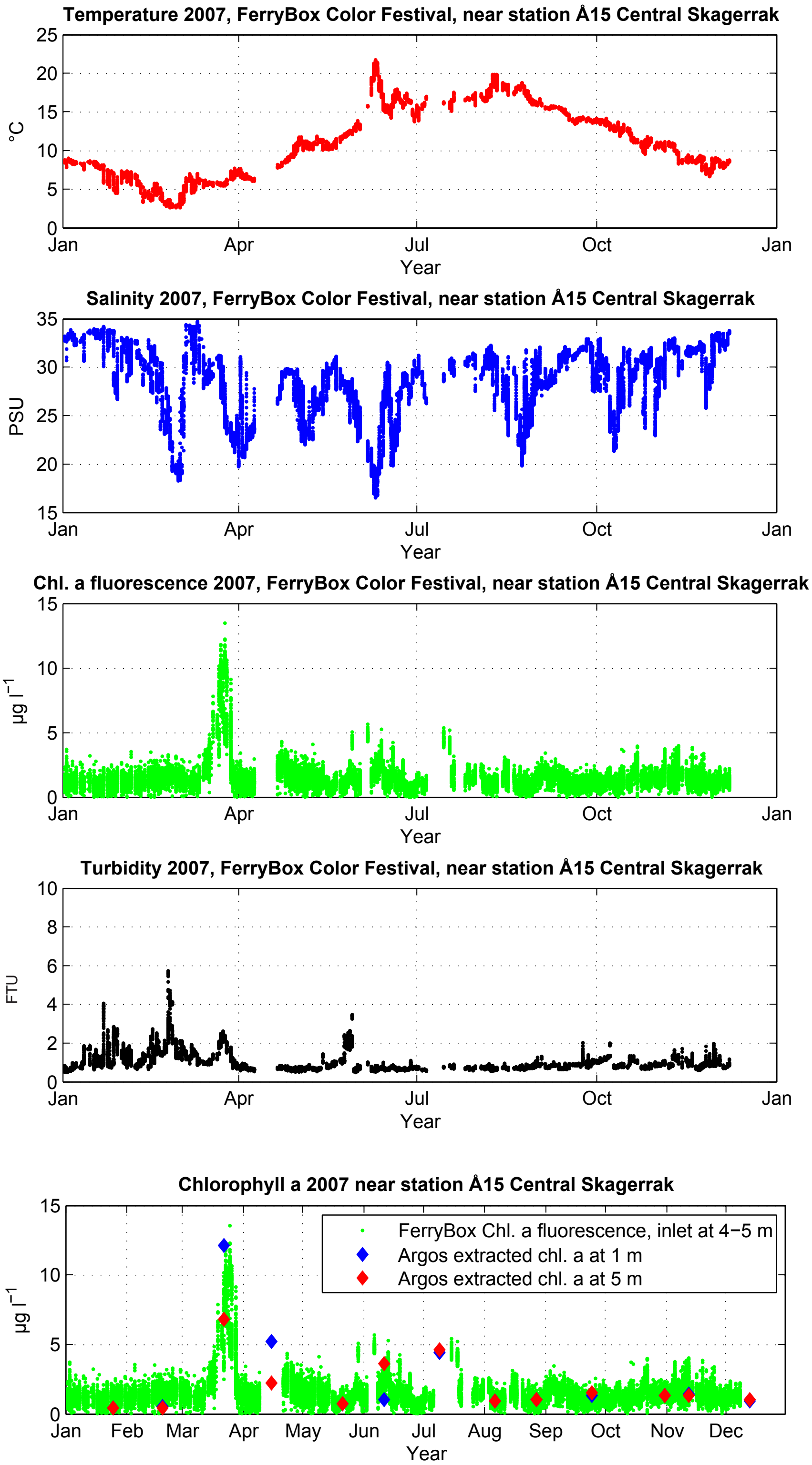


Figure 49. Data from the FerryBox on Color Festival near station Å15 in the Skagerrak in 2007. The lower panel is a repetion of a diagram number three from the top but chlorophyll a data from R/V Argos has been added.

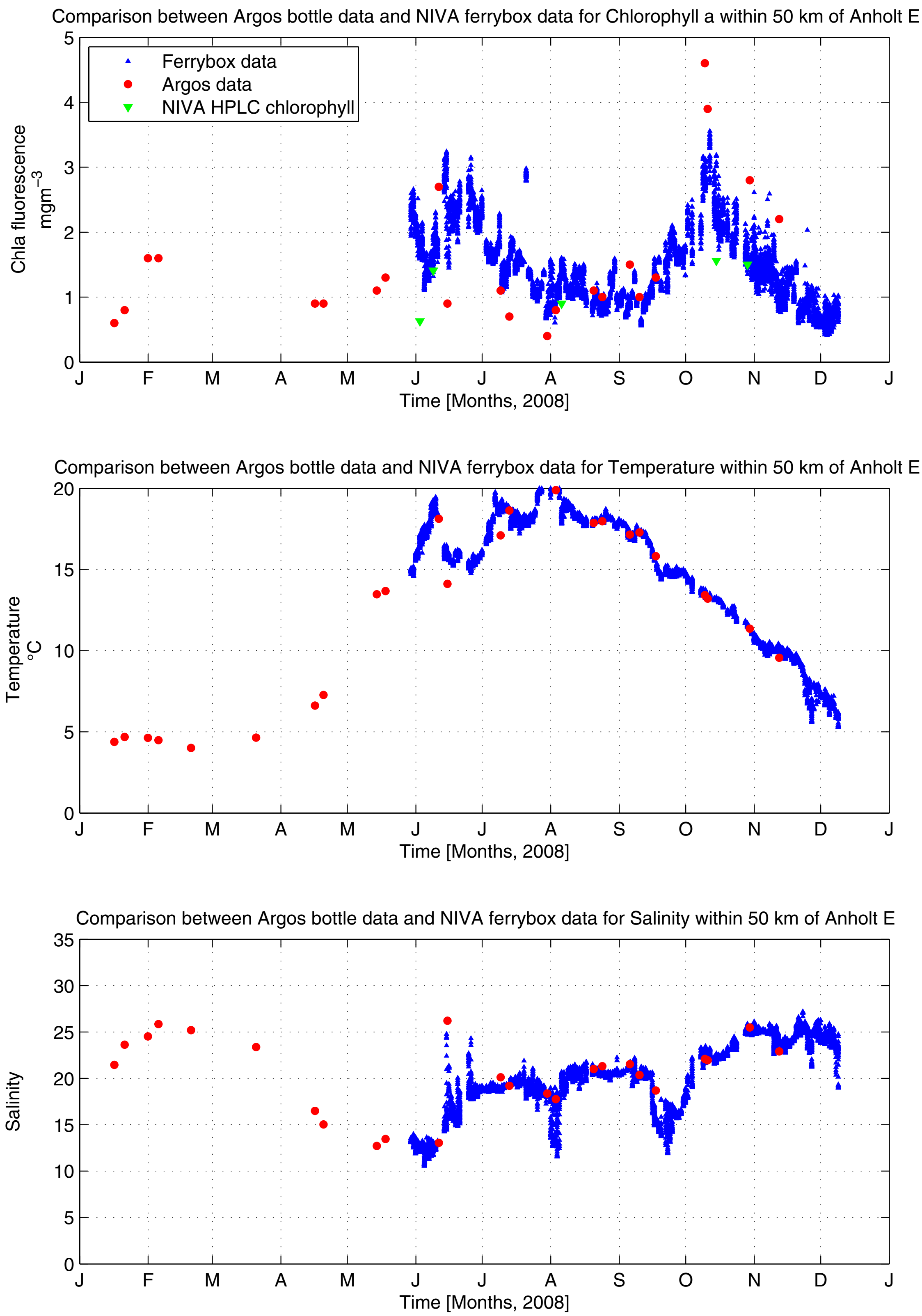


Figure 50. Data from station Anholt e in the Kattegat. Comparison of water sample data from R/V Argos and data from the flow through sensors on Color Fantasy 2008. The FerryBox system on the route Oslo-Kiel was operational from the end of May. The lower HPLC Chl-a data compared to Argos chlorophyll data are as expected since the standard Chl-a methods will be influenced by degradation products-

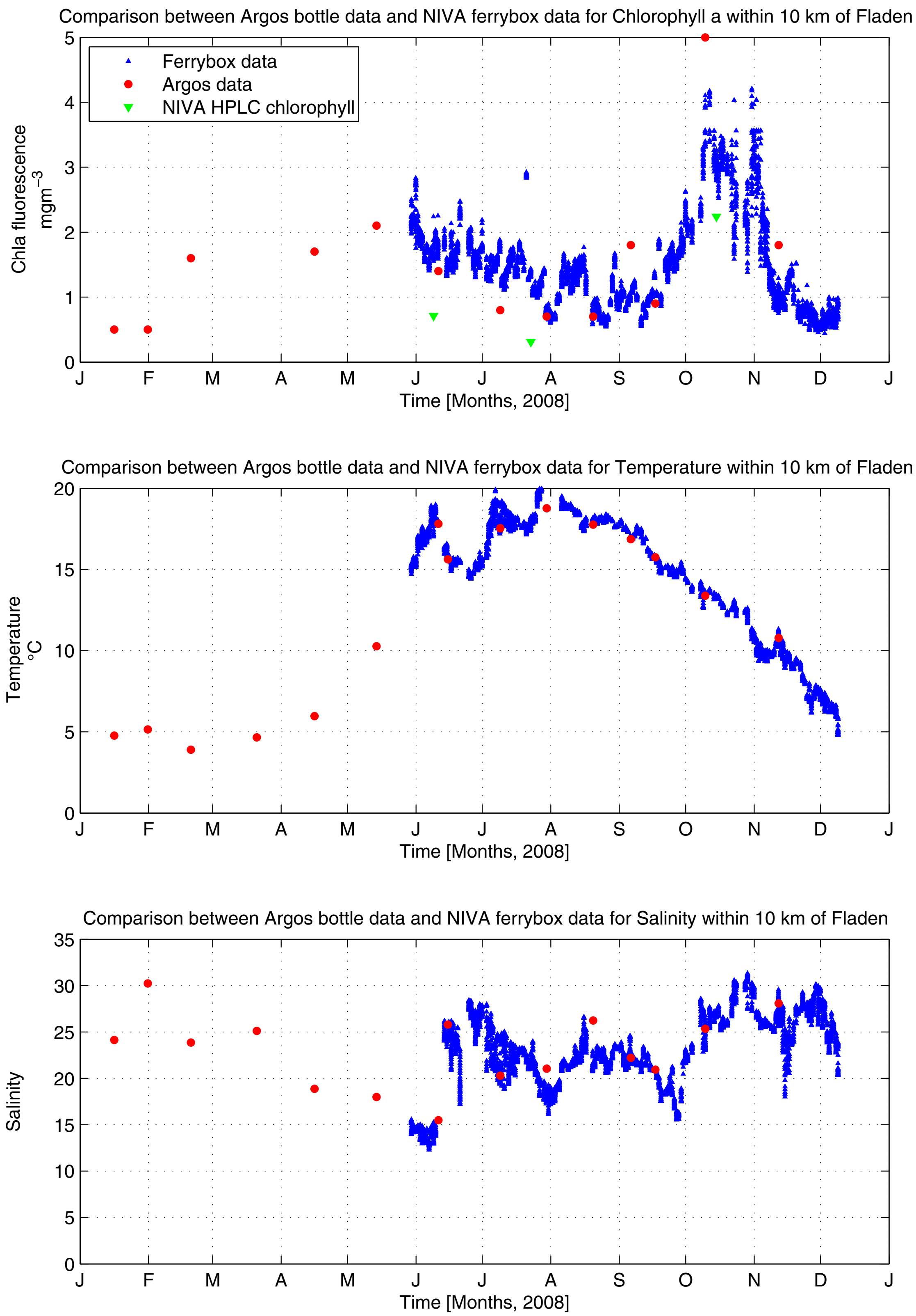


Figure 51. Data from station Fladen in the Kattegat. Comparison of water sample data from R/V Argos and data from the flow through sensors on Color Fantasy 2008. The FerryBox system on the route Oslo-Kiel was operational from the end of May. The lower HPLC Chl-a data compared to Argos chlorophyll data are as expected since the standard Chl-a methods will be influenced by degradation products-

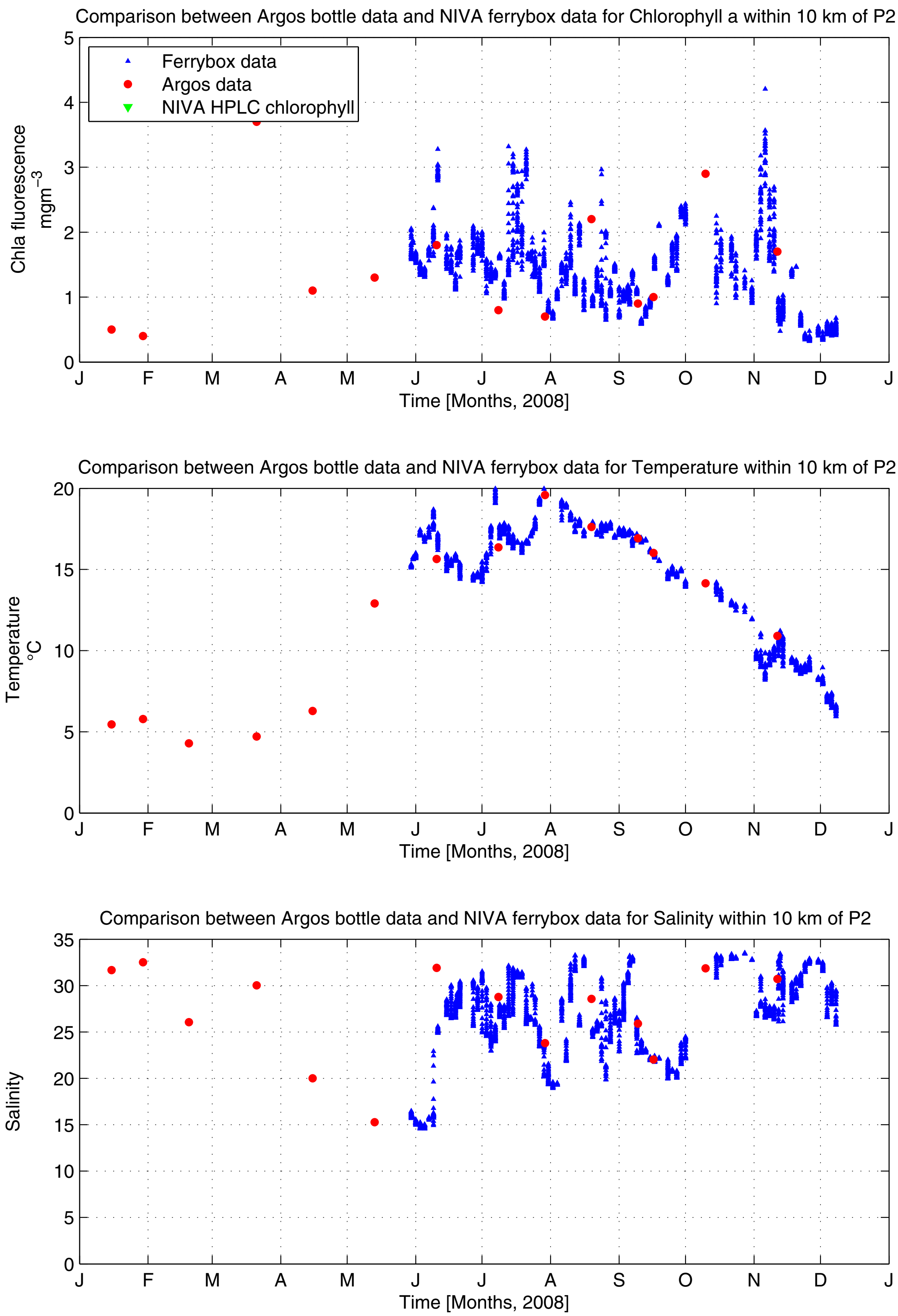


Figure 52. Data from station P2 in the Skagerrak. Comparison of water sample data from R/V Argos and data from the flow through sensors on Color Fantasy 2008. The FerryBox system on the route Oslo-Kiel was operational from the end of May.

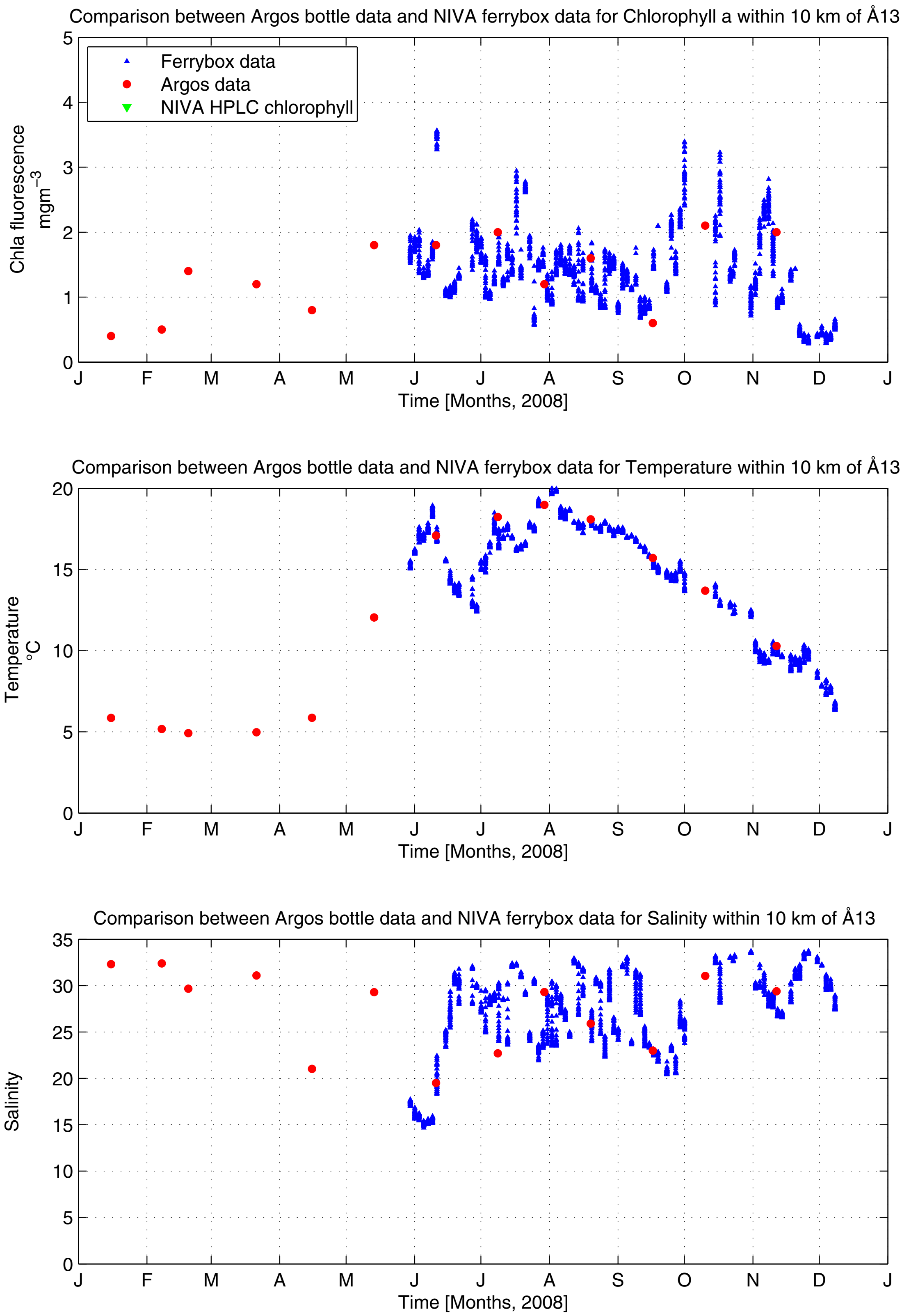


Figure 53. Data from station Å13 in the Skagerrak. Comparison of water sample data from R/V Argos and data from the flow through sensors on Color Fantasy 2008. The FerryBox system on the route Oslo-Kiel was operational from the end of May.

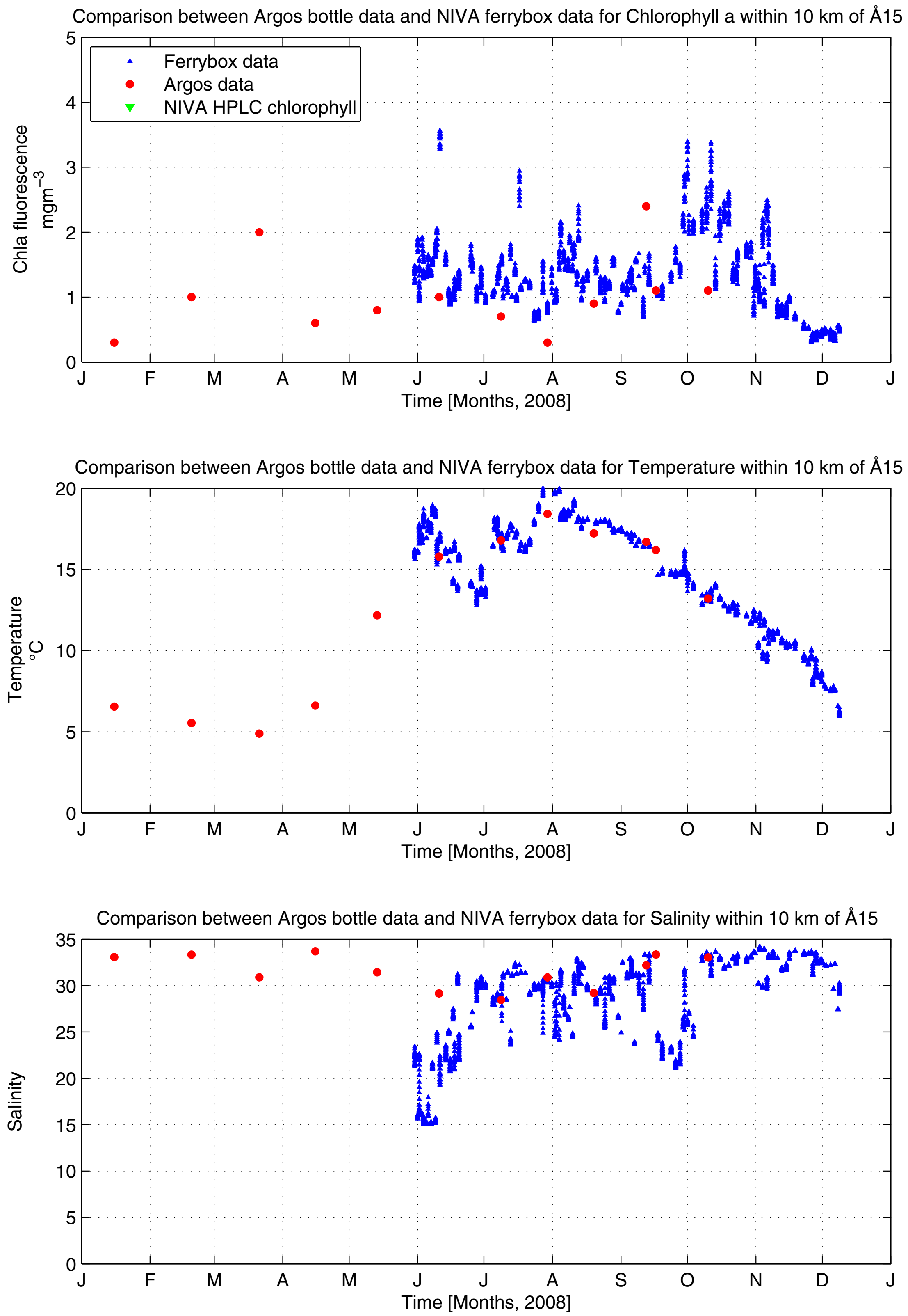


Figure 54. Data from station Å15 in the Skagerrak. Comparison of water sample data from R/V Argos and data from the flow through sensors on Color Fantasy 2008. The FerryBox system on the route Oslo-Kiel was operational from the end of May.

5.2 Comparison of research vessel data from R/V Argos and FerryBox data from the line Helsinki-Lübeck in the Baltic

5.2.1 Alg@line Data Availability

The Finnish Alg@line system has been operational since the first half of the 1990s, and now operates on several vessels, along and across the Gulf of Finland, along the Finnish coast, across the Northern Baltic Proper to Stockholm, and through the Baltic Proper (Helsinki to Travemünde). FIMR has coordinated Alg@line project since 1993. Because FIMR was closed by the end of 2008, Alg@line project activity and coordination is continued in SYKE Marine Centre.

The Travemünde line consists of a pumped system, measuring temperature, salinity, chlorophyll fluorescence and turbidity. Phycocyanin fluorescence has been recorded since 2005. The ferrybox also includes a water sampler, taking samples at fixed points along the route, which are subsequently analysed for nutrients, chlorophyll a and phytoplankton. Observed parameters are listed in table 3, and the positions of the water samples are shown in Figure 55.

Data from 2004 to 2006 were made available. During this period, the sampling regime has changed, with new analyses and instruments being added. Scatter plots, show the availability of data, as well as the development of measured parameters in time and space. Figures 56-62 show the high density of data available, particularly from the automatic systems for temperature, salinity, chlorophyll and turbidity.

5.2.2 Physical parameters

Temperature data from the system appears robust. Values vary between about 0 and 22°C. Warming appears to begin in the south, and autumn cooling in the north. There is relatively little small scale variability apparent, which is to be expected with temperature, which generally varies little over large length scales. Despite this, some detail is apparent, for example in August 2004, near the German coast, where there is local cooling. This is likely to be an area of upwelling.

At first glance, salinity also appears to be reliable. Highest salinities occur in the south, close to the German coast, while a salinity of about 7 is found in the central Baltic Proper. Looking more closely, it is apparent that there are periods where temperature data are available, but salinity data are not, suggesting some problems with the measurement system. Also noticeable is a "fresh" period, with salinities close to 4 throughout the Baltic Proper during August 2005, before a break in the record. This also suggests problems with the measuring system.

Figure 63 shows a comparison between temperature and salinity data (upper panels from each station) collected by SMHI on the U/F Argos, at the stations BY1 in the Arkona Basin, and BY20 in the northern East Gotland Basin. These stations were chosen because they are closest to the Alg@line route. Comparisons were restricted to a maximum time difference of 1 day between sampling. Results show excellent agreement for both parameters. Comparing time series of Argos data with Alg@line data recorded in the same area (Figures 64-66) clearly shows the greater volume of data produced by the high frequency sensors. It also shows the suspected data problems with the Alg@line salinity during autumn 2005.

5.2.3 Chlorophyll concentrations

In the Alg@line system, chlorophyll-a is measured both underway, by a fluorimeter, and from water samples using ethanol extraction. Figure 56 shows data from the former, while Figure 57 shows data from the latter.

Both systems show highest chlorophyll concentrations to occur close to Helsinki, from April to June. Concentrations in the open Baltic Proper are usually much lower at around 2 – 3 mgm^{-3}. The patchiness in the record is apparent in the underway chlorophyll fluorescence data, but not in the water sample data. Time series in Figures 64- 66 also show the high frequency variability in the underway fluorescence which is not picked up by either the "conventional" HELCOM monitoring data or the Alg@line water sample data.

Figure 56 also shows a large number of gaps in the record, particularly when compared to the

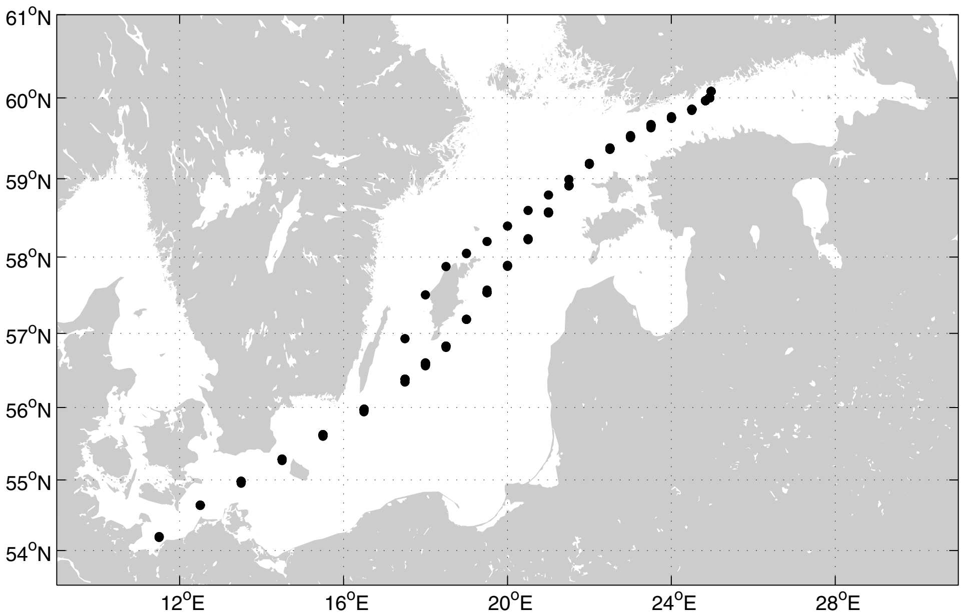


Fig 55. Route of the Alg@line system between Helsinki and Travemünde, showing water sampling positions

Table 3. Sampled parameters on the Helsinki -Travemünde Alg@line ferrybox

Parameter	Frequency	Units
Temperature	3 x per minute, or approximately every 200 metres	°C
Salinity	3 x per minute, or approximately every 200 metres	No units (Practical Salinity Scale)
Chlorophyll a fluorescence	3 x per minute, or approximately every 200 metres	mg m^{-3}
Phycocyanin fluorescence	3 x per minute, or approximately every 200 metres	Arbitrary units
Turbidity	3 x per minute, or approximately every 200 metres	Arbitrary units
Sum of nitrite and nitrate	~12 times per day, equivalent to ~10 – 200 km	mMol m^{-3}
Total nitrogen	~12 times per day, equivalent to ~10 – 200 km	mMol m^{-3}
Dissolved ínorganic phosphorus (orthophosphate)	~12 times per day, equivalent to ~10 – 200 km	mMol m^{-3}
Total phosphorus	~12 times per day, equivalent to ~10 – 200 km	mMol m^{-3}
Chlorophyll-a	~12 times per day, equivalent to ~10 – 200 km	mg m^{-3}
Phytoplankton parameters	~12 times per day, equivalent to ~10 – 200 km	

temperature and salinity data. This suggests that the measurements have not been completely problem-free. The gaps do appear to be less frequent in 2006, suggesting the problems are being overcome. The chlorophyll data from water samples (Figure 57) appear much more reliable.

Comparison between chlorophyll samples collected by Argos and data both from the Alg@line fluorimeter and water samples showed poor agreement. This is most likely explicable by the small number samples available for comparison and due to the rapidly varying, patchy chlorophyll field being sampled. Methodology problems cannot be completely excluded without further analysis, however.

5.2.4 Nutrient data

All Alg@line nutrient data are processed on land from the water samples taken by the automatic sampler on board ship. These samples can be up to 60 hours old before they are analysed. This may affect the data quality.

Nutrient data show the expected seasonal pattern, with nutrient maxima around the end February, and minima in summer months. Total nutrient concentrations are higher than their inorganic components, as they should be. Some isolated problems appear – for example in September 2005 and February 2006. Whether these were due to contamination or some other problem is unclear.

Nutrient sampling regimes have changed frequently during the three years of data supplied. Initially, phosphorus data were collected at all stations throughout the year. Since summer 2005 however, sampling has been reduced during the summer months in the southern Baltic, while the original sampling spacing is retained during winter. The reduced summer sampling programme in the southern Baltic is unfortunate. The development and extent of the phosphorus excess since the 2003 inflows is not well described by only six sample points between the Gulf of Finland and Travemünde. Nitrogen data do not start until summer 2005.

Comparing the nutrient data to Argos observations, there was a problem finding sufficient Alg@line samples close to BY1 or BY20. By extending the search radius at BY20 to 50 km, and accepting all observations within a week (+/- 3.5 days) of an Argos visit, some data were found to make an initial comparison. Based on 7 observations in the Arkona Basin, Alg@line phosphate concentrations were typically 85% of the corresponding Argos concentrations. Total phosphorus concentrations were equal, apart from an offset, whereby Argos data were 0.12 mMol m^{-3} higher than the values from Alg@line. At the Fårö Deep (BY20), agreement between phosphate observations was better: observations differed with an offset of 0.03 mMol m^{-3}.

Insufficient nitrogen data was available to make a comparison.

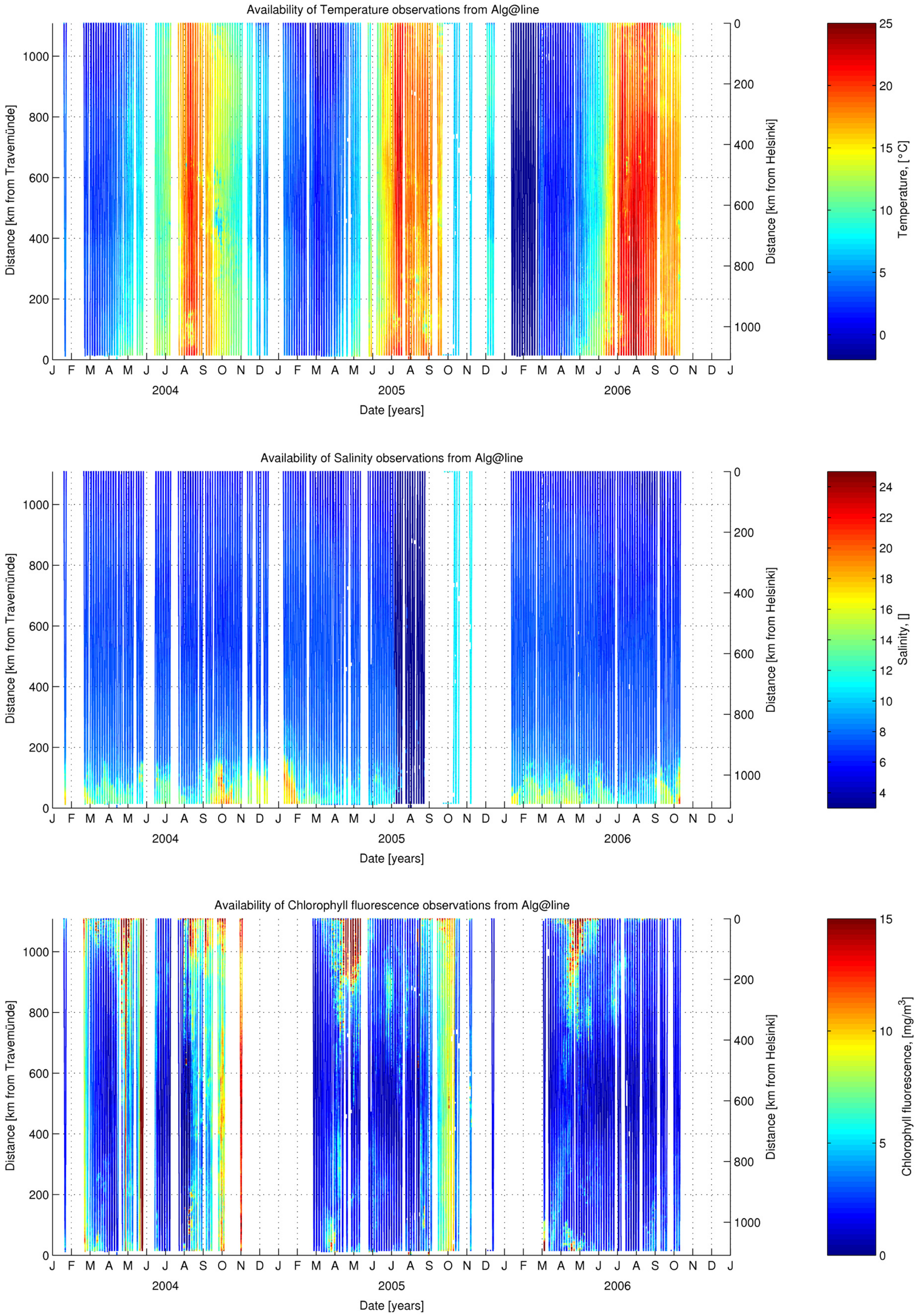


Figure 56 Temperature, salinity and chlorophyll a fluorescence data from Alg@line

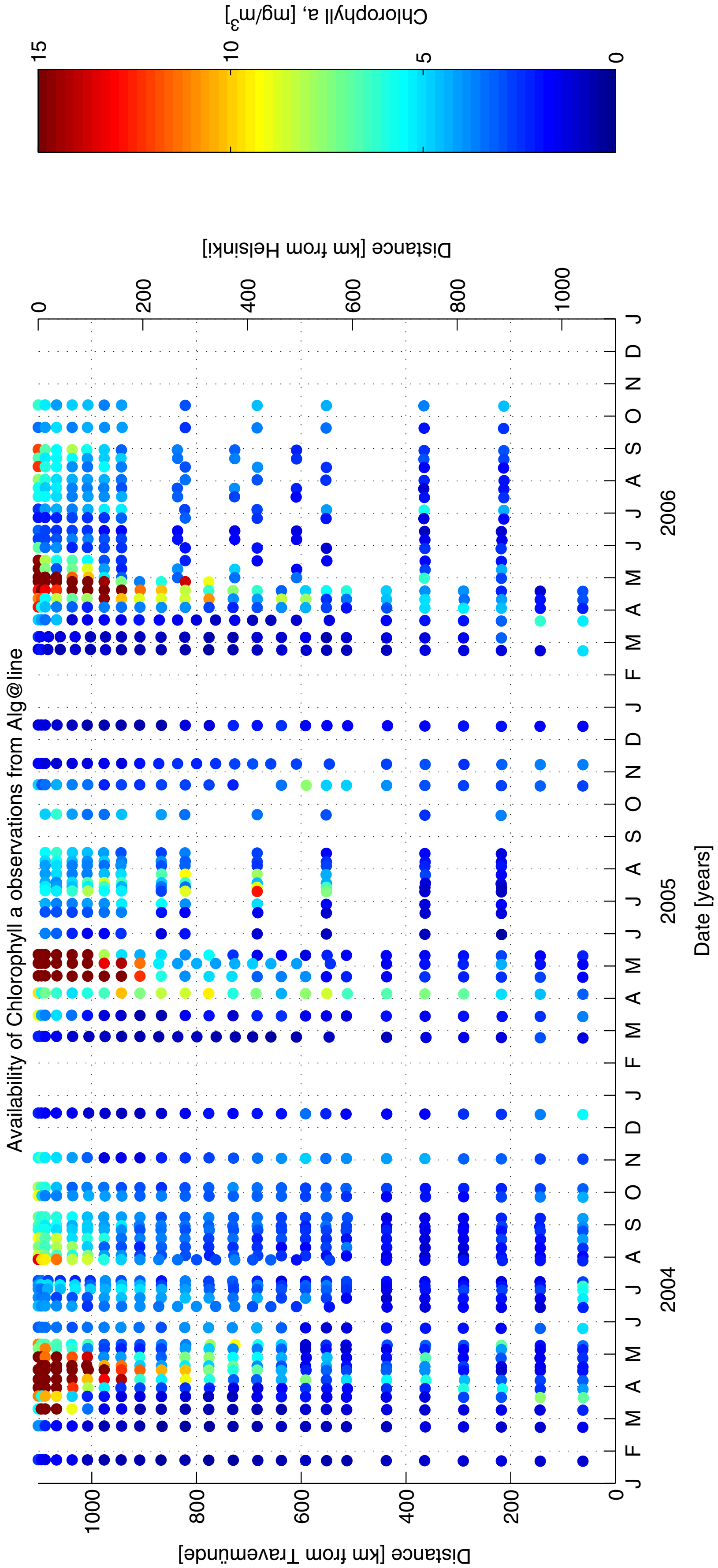


Fig.57.Chlorophyll a data from Alg@line water samples

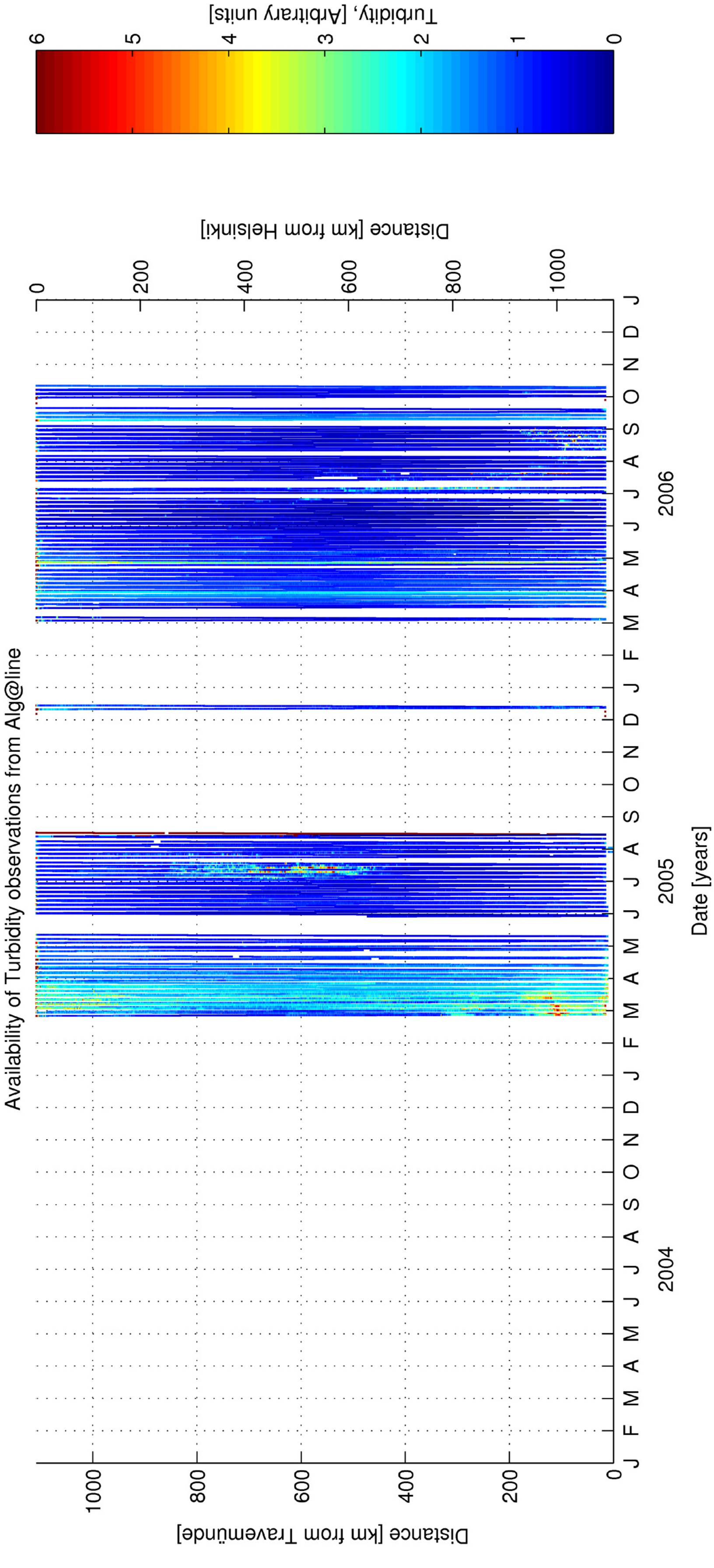


Fig 58. Turbidity data from Alg@line

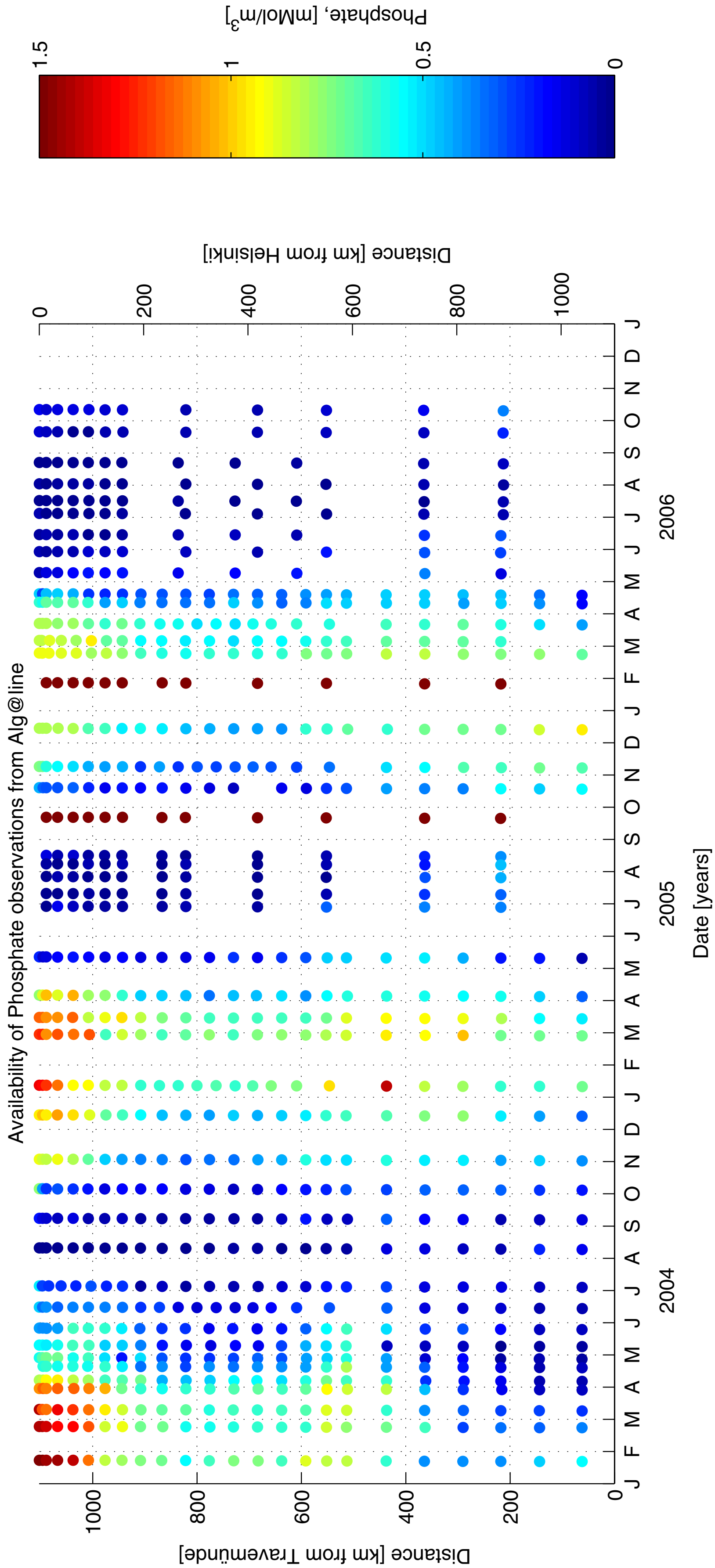


Fig. 59. Orthophosphate data from Alg@line water samples.

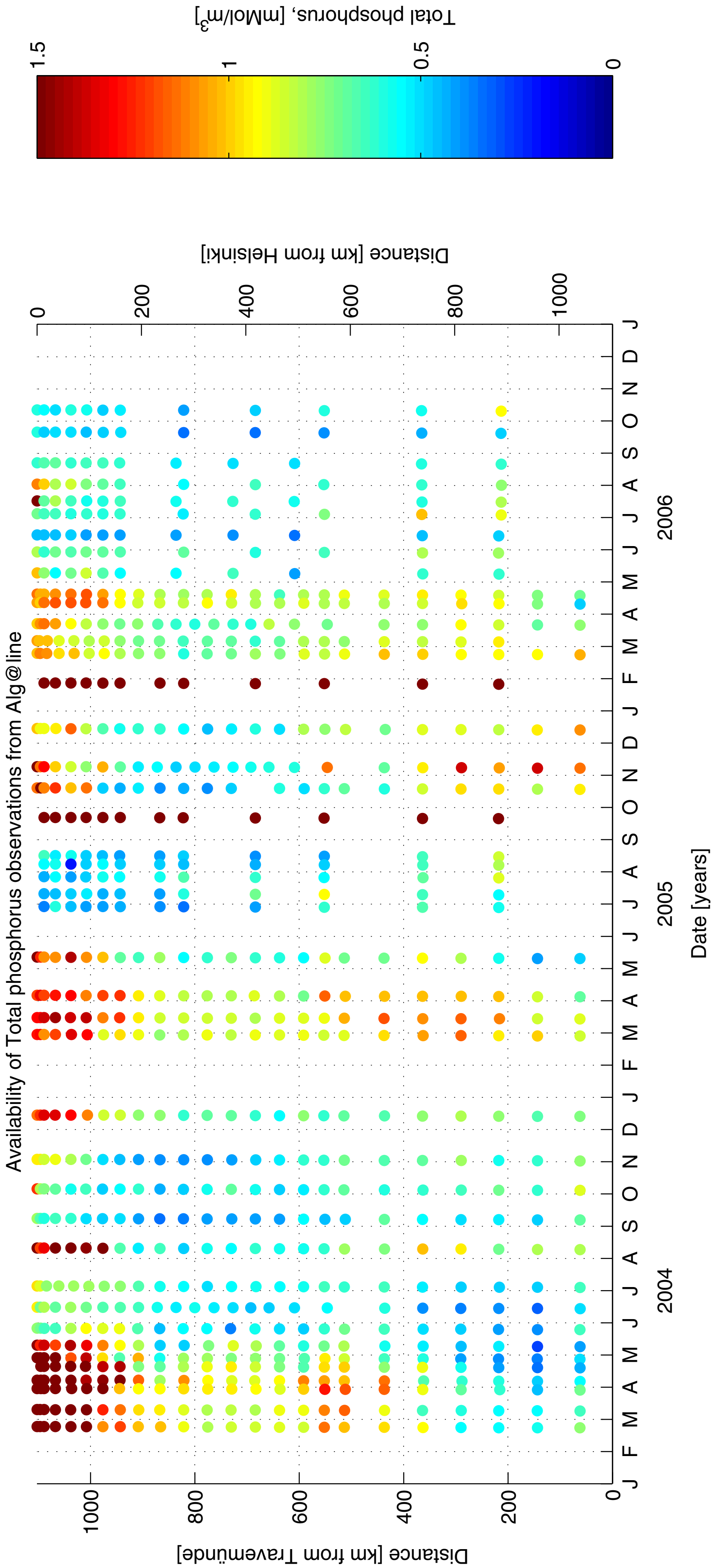


Fig. 60. Total phosphorus data from Alg@line water samples

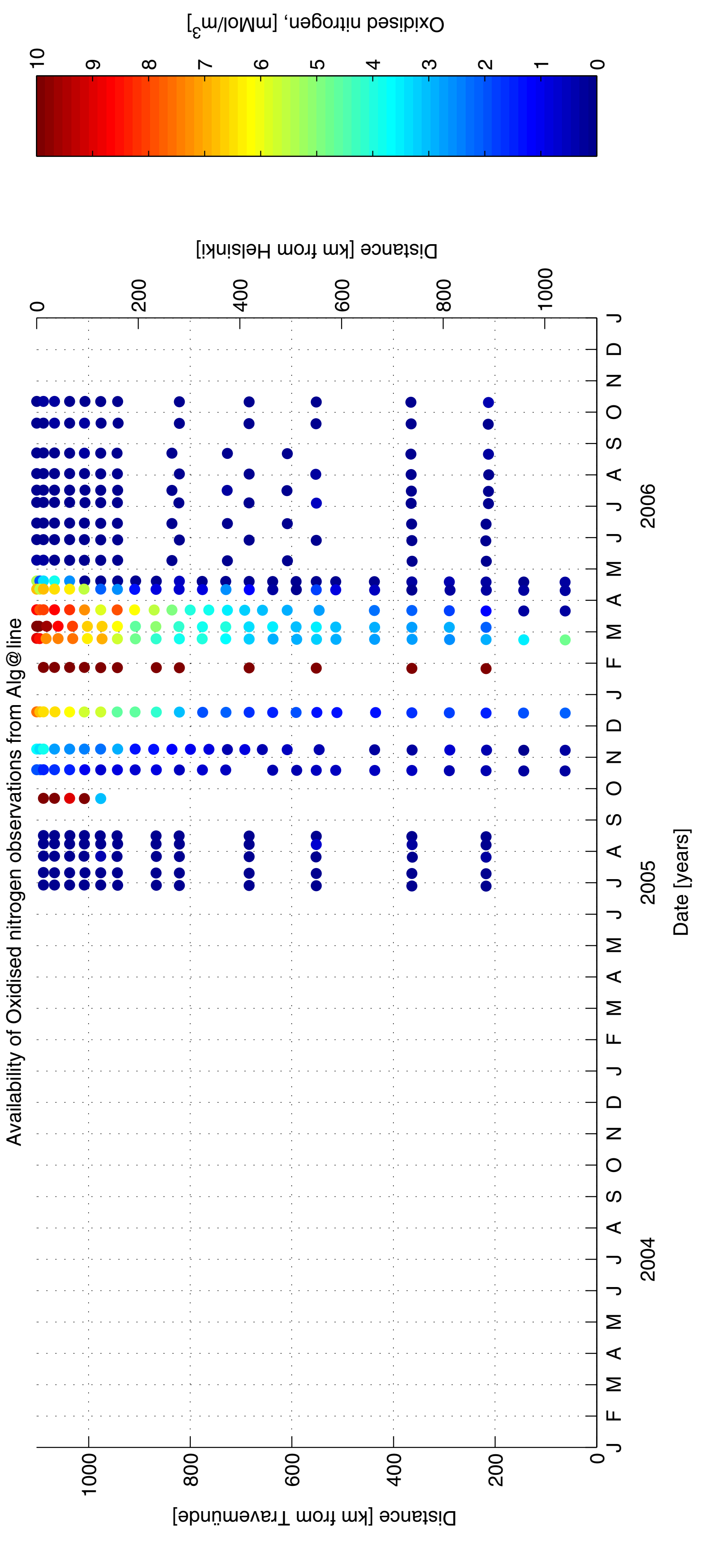


Fig. 61. Oxidised nitrogen (sum of nitrite and nitrate) data from Alg@line water samples

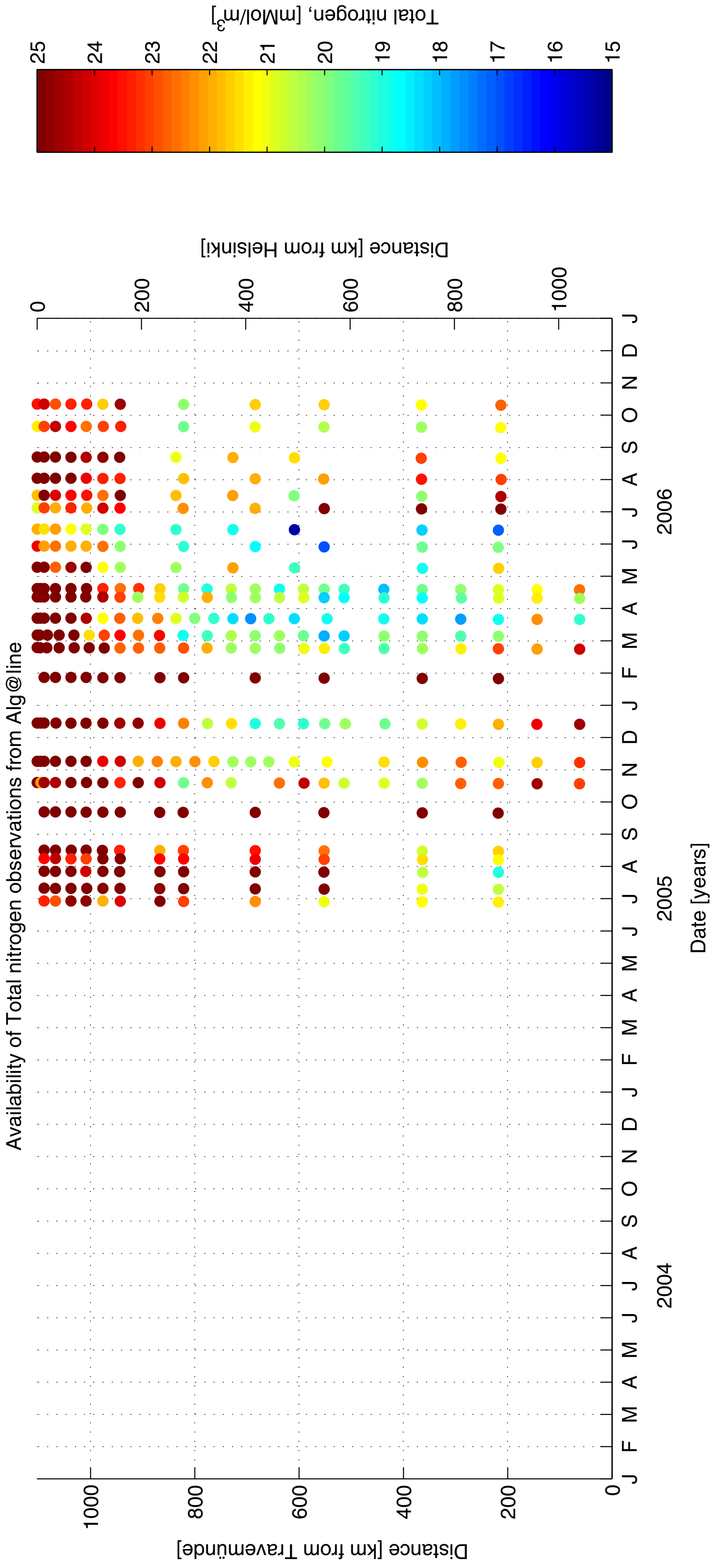


Fig. 62. Total nitrogen data from Alg@line water samples

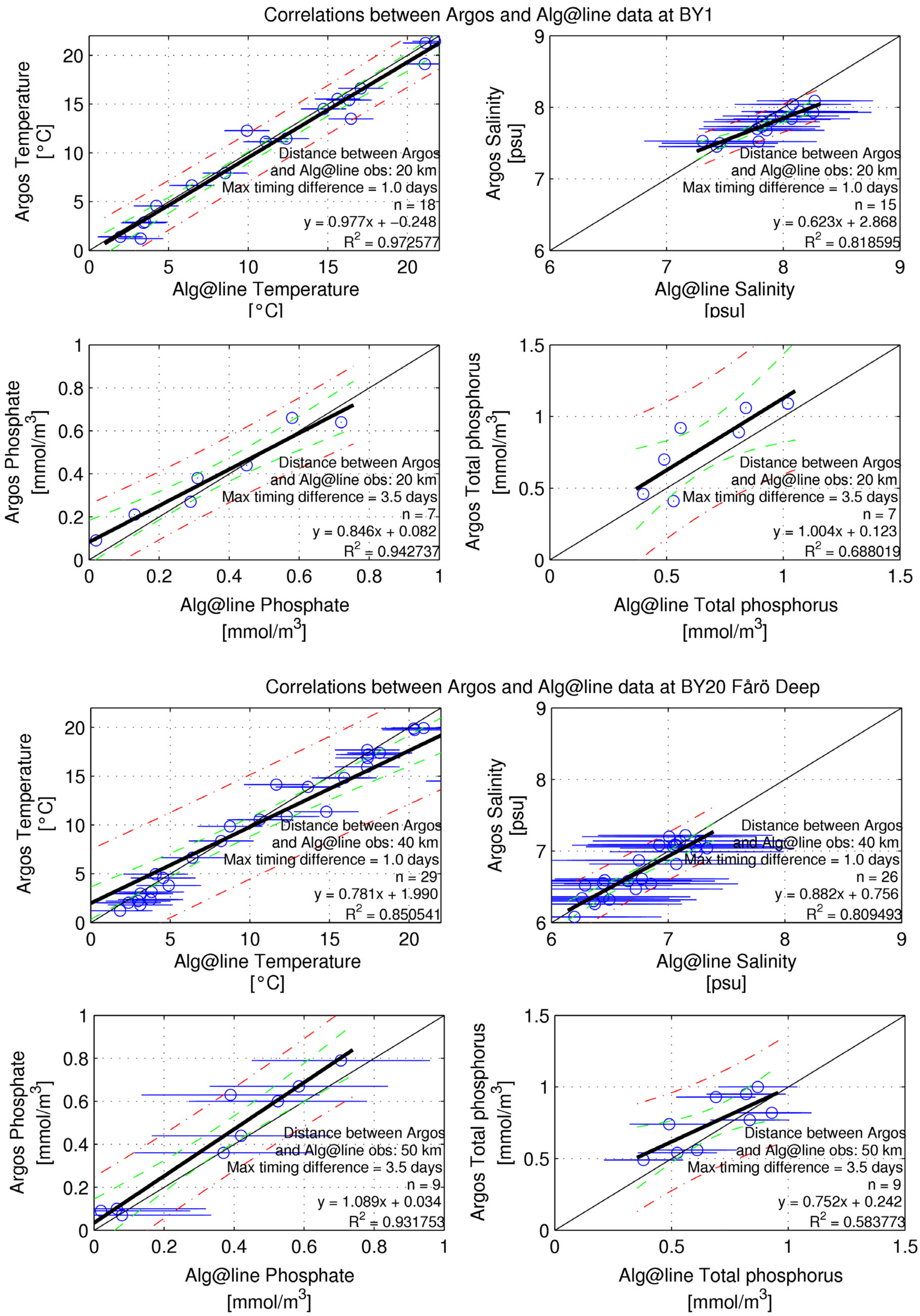


Fig. 63. Comparison between temperature, salinity, orthophosphate and total phosphorus observations from Alg@line and near concurrent observations from U/F Argos. Straight horizontal lines indicate the 95% confidence interval for Alg@line data. U/F Argos data collected from 5 metres depth, using water bottles. Temperature measured with electronic reversing thermometers, salinity with a Guideline salinometer, and phosphate/total phosphorus with autoanalyser using COMBINE manual methods

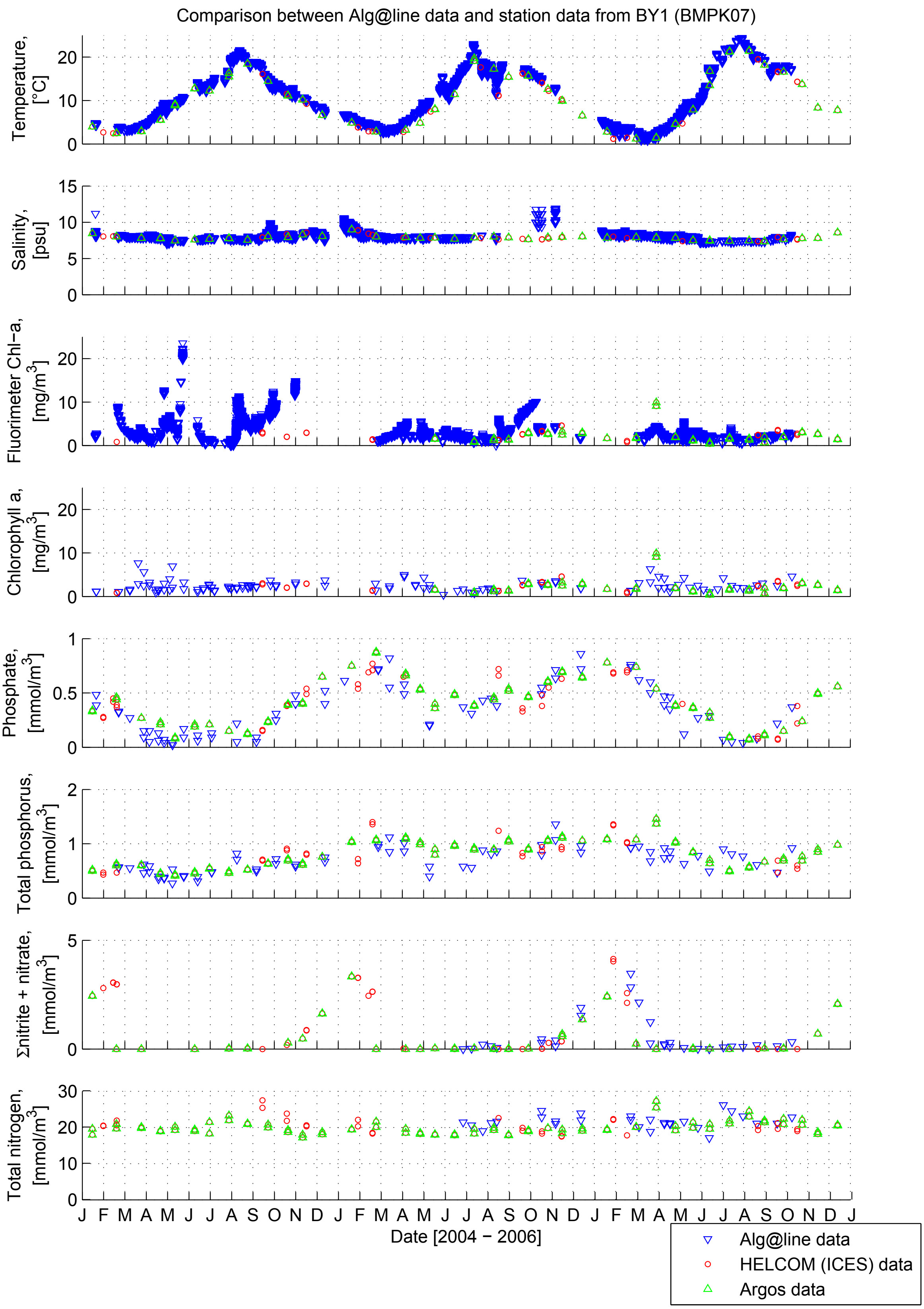


Fig. 64. Time series showing a comparison between Alg@line and HELCOM data at BY1.

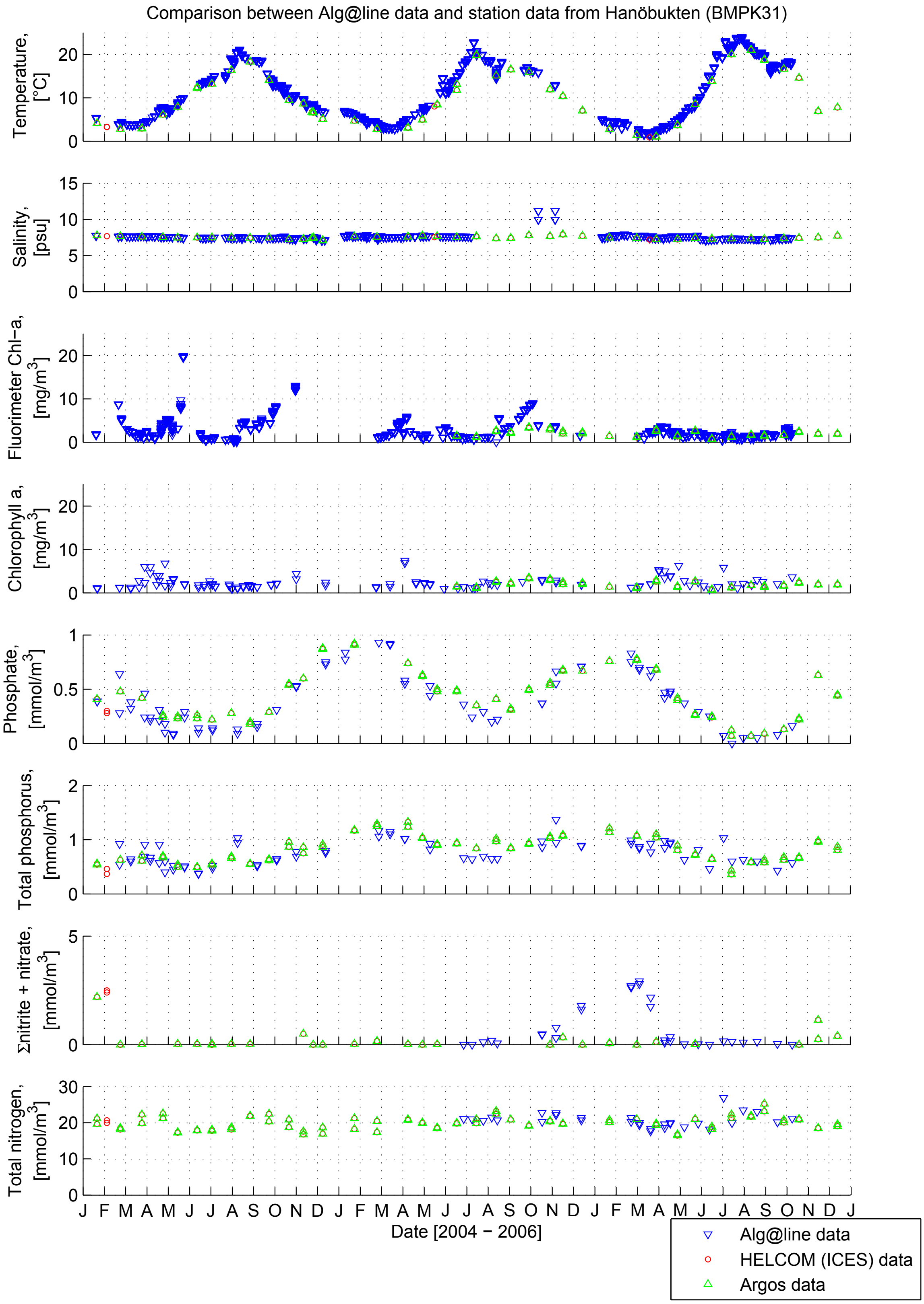


Fig. 65. Time series showing a comparison between Alg@line and HELCOM data at Hanöbukten.

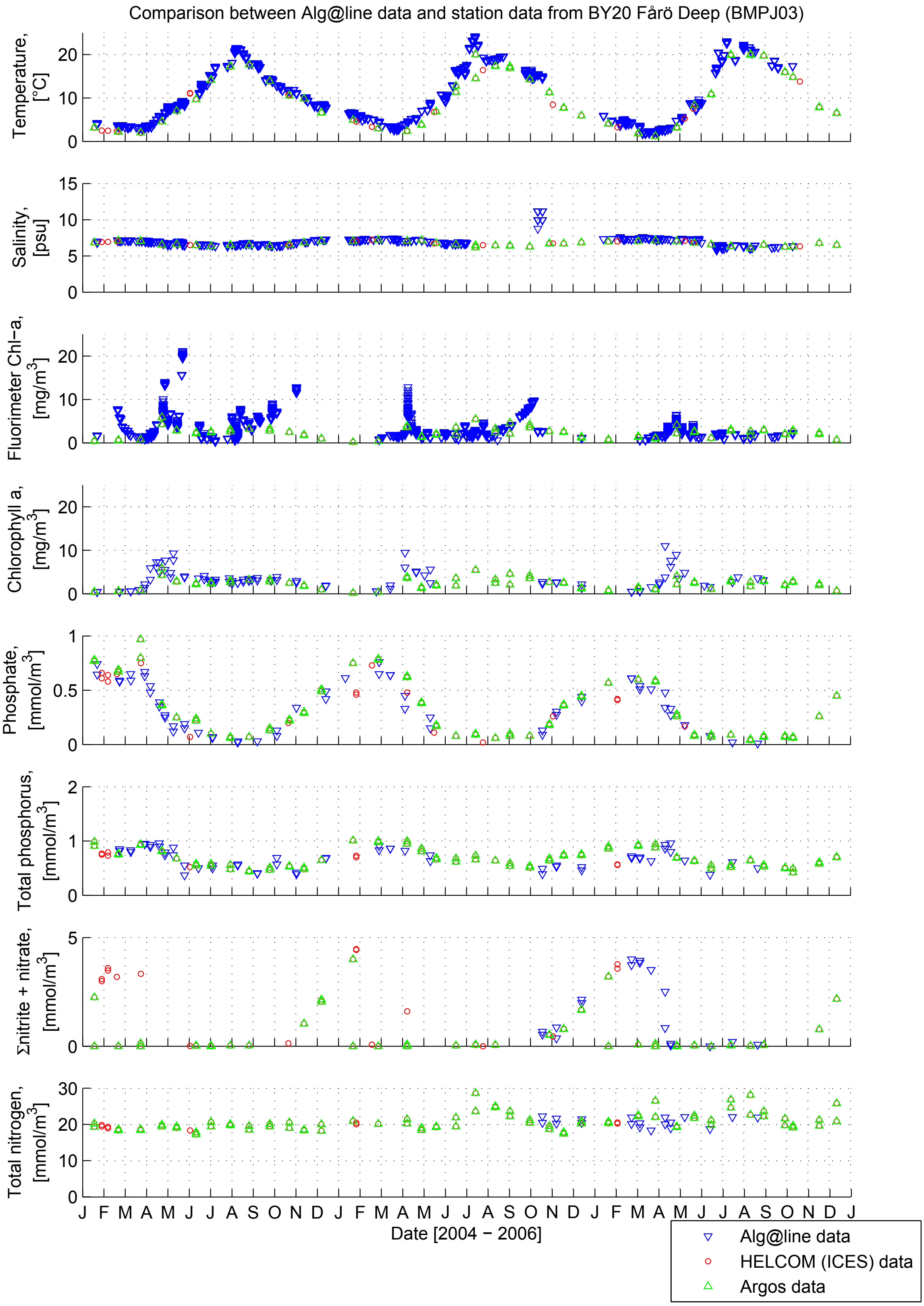


Fig. 66. Time series showing a comparison between Alg@line and HELCOM data at BY20.

6 PROPOSED ENVIRONMENTAL STATUS INDICATORS

6.1 Introduction

Environmental status indicators meet several needs. Well-chosen indicators illustrate the interactions between society and the environment, and can illuminate various stages of the DPSIR (Drivers, Pressures, States, Impacts, Responses) framework. Indicators may be measured values (e.g. nutrient concentrations) or may be derived products (e.g. total area of anoxic bottom water, or cyanobacteria bloom index). Indicators are management tools, illustrating, and perhaps simplifying, a description of the environment in such a way as to allow society to take action to safeguard ecosystem services. While a single indicator describing ecosystem health would be attractive, it would be difficult to interpret in such a way as to clearly indicate what remedial activity could be taken. Thus we need a whole suite of indicators, describing the physical, chemical, biological and societal forcing (drivers and pressures) and another suite to describe the environment condition (states and impacts). This multitude of indicators creates a dilemma: many indicators require interpretation, but allow specific problems to be identified, while a single state indi-

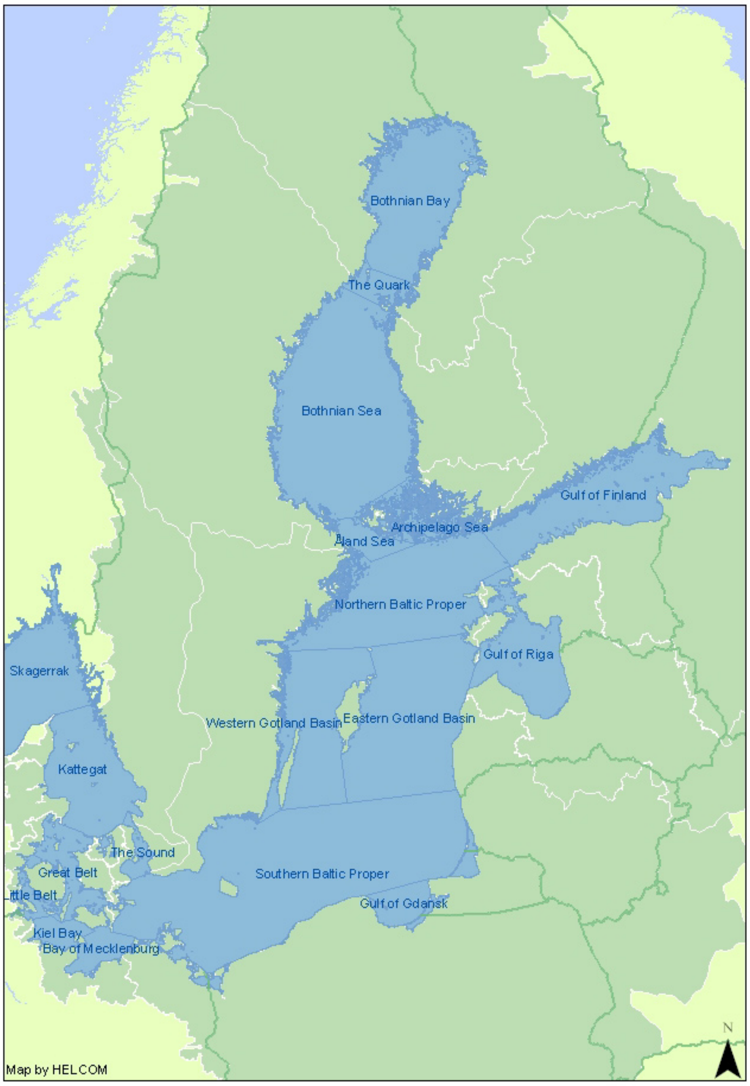


Fig. 67. Map showing the HELCOM division of the Baltic Sea and the Kattegat and the Skagerrak. Source www.helcom.fi. These main sea areas are used for the indicators decribed in tables. 5-6 and 8-9.

cator is attractive, but does not give guidance as to the cause of a problem.

This chapter presents a range of indicators to meet these needs. Some indicators exist already, and are used by the EEA, HELCOM and/or OSPAR, while others are new.

6.2 Drivers and pressures

6.2.1 Atmospheric drivers

Table 5 presents a list of potential indicators describing the atmospheric forcing on the system.

6.2.2 Physical drivers and state indicators

In addition to the meteorology, the Baltic is forced by freshwater run-off and the estuarine circulation in the Kattegat and Danish Straits. Exchanges between basins are implicated in the spread of nutrients and larvae, while the Baltic outflow itself is a vital parameter for numerical models of the North Sea, which are run both in Sweden and by OSPAR partners.

The physical state of the Baltic Sea limits the extent and production of many species. Where primary productivity is considered to be limited to the surface mixed layer, the mixed layer depth is important. The strength of stratification restricts the vertical transport of nutrients and oxygen, although upwelling is locally important, particularly along the Swedish east coast and in the Hanö Bight. An upwelling index, based on the temperature difference between upwelled and surrounding water, and taking into account the duration of the event would assist in understanding the transport of nutrients to the surface waters. Temperature and upwelling information can be obtained from satellite sea surface temperature products, numerical models and well located buoys. The vertical stratification also influences the fate of saline inflows. Weak stratification in the East Gotland Basin leads to inflows covering the basin floor, rather than penetrating the halocline. The development of surface and deep water salinity in each basin is a useful indicator.

A potential mechanism for phosphate transport from deep water may be the area of bottom within the pycnocline/redoxcline: as the bottom is covered by anoxic water, phosphate is freed into the water column, with some being readsorbed as the anoxic water recedes. Such a process could be maintained by internal waves on the pycnocline, which can only be resolved with high frequency measurements from buoys or landers, and are not resolved by models.

Cod reproduction is restricted by the spring/summer oxygen concentration (depth of the 2ml/l oxycline) relative to the position of the 11 psu halocline, so the depths of these parameters, as well as the available reproduction volume in each basin are important explanatory variables for cod recruitment.

The physical forcing and state indicators are summarised in table 6.

6.2.3 Chemical State and Forcing Indicators

The physical exchange indicators are of most interest when related to nutrient concentrations, to indicate volume transports of nutrients. It is therefore desirable to have a nutrient input indicator, related to observed or modelled discharges of nutrients from rivers. This is available from existing data sources (SLU, or the SMHI HOME-Vatten modelling system). Similarly, the ferrybox systems (Stockholm – Mariehamn and Varberg Grenå) should be equipped with nutrient samplers. Estimates of the amount of upwelled nutrients may be obtained from buoy-mounted nutrient analyzers, or through combining ferrybox nutrient observations (in the West Gotland Basin) with satellite and model data. These would be able to capture the short term nature of these events.

The magnitude of the winter nutrient pool in surface waters is a limiting factor for much phytoplankton production, while the amount of excess phosphorus is a useful canary, warning of the potential for cyanobacteria blooms during the following summer. While monthly sampling from research vessels is useful (particularly in indicating vertical nutrient gradients) higher frequency systems, such as those mounted within ferryboxes

Table 5. Proposed in air climate indicators for the main sea areas surrounding Sweden.

Indicator group	Indicator	Data source	Comments
Irradiation	PAR Global irradiation UV-B UV-A	These indicators can be obtained from either observations or from numerical models (e.g. SMHI Strång model).	These indicators illustrate limiting factors in phytoplankton growth.
Wind	Monthly mean/maximum Annual mean/maximum Gale days Storm days Hurricane days Monthly mean direction Monthly peak direction Annual mean direction Annual peak direction	Data for these indicators are available from a limited number of offshore platforms, but also from numerical models, such as HIRLAM	These climate indicators show the relative storminess, which affects both horizontal and vertical advection. The direction of the monthly maximum event (peak direction) influences the growth of waves, and resulting mixed layer development
Other weather parameters	Air temperature Air pressure (including Baltic Sea Index) Humidity Cloud cover	These indicators may be obtained from observations and from numerical models, such as HIRLAM. The MESAN system at SMHI combines observation data and model results.	The Baltic Sea Index is an indication of the balance between the north-south and east-west pressure gradients, and an indicator of wind forcing – particularly related to saline inflows. Cloud cover is important for the development of algal blooms.
Atmospheric chemistry	pCO_2 (mean, min and max)	Measurement stations, ideally one on the west coast and one representative for the Baltic.	pCO_2 is a significant driver of the carbonate cycle in the Baltic, affecting pH and with it, larval fish and shellfish development
	NO_x and NH_x deposition	Data are available from numerical models, such as the SMHI MATCH model.	Atmospheric deposition of nitrogen is a significant nutrient source in the Baltic.

can give a more detailed picture both spatially and temporally. They may even highlight some of the processes by which the surface nutrient pool is recharged.

Nutrient consumption has been used to give an estimate of primary production. Using the Redfield ratio, the consumption of nitrate and phosphate can be used to estimate the production of carbon. The difference between winter and summer total nutrient concentrations can indicate where other forms of nitrogen and phosphorus are used.

Nutrient concentrations are themselves a direct indicator of eutrophication, so are of direct interest to decision makers – particularly regarding the Swedish environmental target “No eutrophication”. As such, winter DIN, DIP, silicate, total nitrogen and total phosphorus concentrations in surface waters, and their temporal trends, are important.

Oxygen concentrations are an indirect indicator of eutrophication, both as a driver and as recipient. The spring phytoplankton bloom leads to the super-saturation of oxygen, and oxygen satura-

Table 6. Physical forcing and state indicators

Indicator group	Indicator	Data source	Comments
Inputs	Fresh water run-off, by basin	Daily observations in Sweden, SMHI's HBV model for the remainder of the drainage basin	
Exchanges	Baltic inflow/outflow	Sea level difference between Viken and Landskrona	Sea level difference along Öresund has proven to be a good indicator of the barotropic exchange, but baroclinic inflows have passed unnoticed
	Baltic inflow penetration	Buoy located in the Bornholm basin, with salinity and oxygen sensors	
	Exchanges between the principle basins: Gulf of Bothnia – Baltic Proper	ADCP mounted on the Stockholm – Mariehamn – Helsingfors (alternatively, Stockholm, Mariehamn – Tallinn) ferrybox, for exchanges	
	Transport through the west Gotland Basin	ADCP mounted on a ferrybox between Nynäshamn and Visby, or Oskarshamn and Visby.	
	Exchanges between Bornholm Basin and south eastern Baltic Proper	ADCP mounted on Karlskrona-Gdynia ferry	
	Exchanges between the principle basins: Baltic – North Sea	ADCP mounted on a ferrybox between Varberg and Grenå	
	Baltic outflow	Buoy located in the Baltic current, north of Gothenburg	
State	Mixed layer depth	Existing research vessel observations	
	Stratification strength	Existing research vessel observations	
	Upwelling index	Based on modelled data, satellite and/or buoy observations	
	Surface and deep water salinity	Existing research vessel observations	
	Depth of the 2 ml/l oxycline	Existing research vessel observations	
	Depth of the 11 psu halocline	Existing research vessel observations	
	Cod reproduction volume	Existing research vessel observations	
	[Bottom area within the pycnocline/ redoxcline]	Existing research vessel measurements	A tentative indicator, which requires further investigation as to its value

Table 7. Proposed in water oxygen and nutrient indicators. A combination of measurements from research vessels, FerryBox systems and instrumented moorings is used for measurements.

Indicator group	Indicator	Data source	Comments
Nutrient inputs	Nutrients from land	Model data and observations from SLU, SMHI and TRK, giving monthly direct and indirect discharges to each sea area. Atmospheric deposition has already been presented under 'atmospheric forcing'	
	Assimilated nitrogen	Estimate of nitrogen fixed by cyanobacteria, based on numerical models.	
Oil spills	Frequency and duration	Observed by instrumented buoy.	Possibly augmented by information from the Swedish Coastguard (e.g. SAR & visual observations)
Acidification	pH, alkalinity and/or pCO2	Research vessels, but also ferrybox systems	Automatic measurements need to be as stable as those achieved by the standard HELCOM method
Nutrient fluxes	Volume transport of nutrients	DIN and DIP observations on ferryboxes (Mariehamn – Stockholm; Nynäshamn/ Oskarshamn - Visby; Karslkrona Gdynia; Varberg – Grenå)	
	Nutrient export through the Sound	Observations of currents and nutrient concentrations in Öresund, using Argos with ADCP or sea level difference observations	
	Export of nutrients to North Sea	DIN and DIP measured on buoy in Baltic Current, north of Gothenburg	
	Nutrient budget	Based on the previous indicators	Estimates of nutrient inputs and exports to/from the system,
	Nutrient upwelling	Modelled, satellite or buoy observations. FerryBox observations (Oskarshamn – Visby) would be useful.	Estimate of the supply of nutrients to surface waters by upwelling
Nutrient status	Winter nutrient concentrations in surface waters + trends + spatial distribution	Research vessel & regional estimates of DIN, DIP, Si, TotN and TotP should be augmented by ferrybox and buoy observations of DIN and DIP.	Where observations are unavailable, or numerical model data are considered reliable, they can be used. Mapping nutrient distributions allows the identification of hotspots.
	Winter nitrogen to phosphorus ratio	Research vessel, regional, buoy and ferrybox observations	Allows estimates of potential cyanobacteria bloom intensity, also identifies longer term changes in ecosystem structure.
Nutrient consumption	Difference between winter and summer DIN, DIP, TotN, TotP, Si	Research vessel, regional, buoy and ferrybox observations	Estimates of the spring carbon production, based on Redfield. Silicate consumption may indicate fraction of diatoms in phytoplankton class structure
Oxygen concentration	Day time oxygen anomaly in surface waters	Research vessel, regional, buoy and ferrybox observations,	Combining this with knowledge of wind speed, mixed layer depth and sea surface temperature gives an estimate of primary production (Bargeron et al, 2006)
	Area and volume of anoxic/hypoxic water	Research vessel, regional and buoy/lander observations	
	Duration, frequency and severity of hypoxic events	Buoys/landers in the Bornholm Basin and southern Kattegat (Laholm and Skälderviken) and around the redoxcline in the Baltic Proper,	Numerical models would need to be internal wave resolving, which would require much finer vertical and horizontal resolution than is currently available

Table 8. Proposed phytoplankton based indicators. A combination of measurements from research vessels, FerryBox systems and instrumented moorings is used for sampling and measurements.

Indicator name	Indicator description/comment
Primary production indicators	
Monthly production	CO_2-uptake incubations
Yearly production	CO_2-uptake incubations
Monthly surface oxygen anomaly	O_2 measurements etc.
Fluorescence techniques to be evaluated	FFT
Natural nitrogen input indicator	
Biomass of nitrogen fixing cyanobacteria	Microscopy and estimates using phycocyanin fluorescence
Winter phytoplankton blooms	
Phytoplankton biomass	
Phytoplankton composition	
Spring bloom	
Time of start	>5 µg chl a per litre, see Fleming & Kaitala
Time of peak	(threashold to be determined in the Skagerrak-Kattegat)
Length of bloom	
Maximum oxygen anomaly	
Maximum pCO_2-depletion	
Phytoplankton composition	see biodiversity indicators
Phytoplankton biomass	
Phytoplankton community composition	Ratio biomass dinoflagellates:total phytoplankton
	Ratio biomass diatoms:total phytoplankton
Summer phytoplankton	
Phytoplankton composition	see biodiversity indicators
Biomass - Chlorophyll a	Chl. a fluorescence calibrated with water sample ananyses
Biomass - biovolume	HELCOM-biovolumes
Phytoplankton community composition	Ratio biomass cyanpbacteriea:total phytoplankton
	Ratio biomass dinoflagellates:total phytoplankton
	Ratio biomass diatoms:total phytoplankton
Autumn bloom	
Time of start	
Time of peak	
Length of bloom	
Phytoplankton composition	see biodiversity indicators
Phytoplankton biomass	
Phytoplankton community composition	Ratio biomass dinoflagellates:diatoms
	Ratio biomass diatoms:total phytoplankton
OSPAR phytoplankton biomass indicator	
Growing season mean chlorophyll a	
Biodiversity indicators	
New phytoplankton species observations	
Stability of phytoplankton and microzooplankton community structure	Spring bloom, post spring bloom, summer and autumn
Stability of zooplankton community structure	Spring bloom, post spring bloom, summer and autumn
Acidification indicators	
Coccolithophorid cell numbers	
Coccolithophorid species composition	
Coccolithophorid bloom area and length of bloom	
Harmful Algal Event indicators	
Nodularia spumigena biomass	
Surface coverage and lenth of of cyanobacteria bloom	
Toxin Producing Algae (TPA) presence	
Fish killing species presence	
Fish mortality events	number of events per year
Toxic shellfish events	number of events per year
Human illness events	number of events per year

tion, with wind speed, sea surface temperature and mixed layer depth has been used as an indicator of primary production in ferrybox systems (Bargeron et al, 2006). This method could be evaluated for the Baltic using existing data.

As anoxia is associated with large amounts of phosphorus (but also silicate and ammonium) from bottom sediments, the area and volume of anoxic water in each basin is important as a driver of eutrophication. Hypoxia destroys benthic communities. Short term events change animal behaviour, while longer term events cause kills and changes to population structure. While hypoxia may be caused by eutrophication, or just hydrography, its impact is such that it is an indicator of healthy ecosystem function. The duration, severity and frequency of hypoxic events are valuable indicators. Existing ship based measurements have been successful in mapping the extent of anoxic bottom water, but do not sample at the sediment/water interface – where the benthos live. Present observations are also too infrequent to observe the frequency of hypoxic events, particularly near the halocline. This can only be achieved by in situ oxygen sensors, mounted on buoys or landers. Given the intermittent nature of hypoxia in the Bornholm basin, and its importance to cod reproduction in the Baltic, it is recommended that the Baltic Inflow Penetration buoy described in 8.2.2 be equipped with oxygen sensors. Such a buoy would also allow better determination of the cod reproductive volume.

Ocean acidification is now an important issue, with recent studies in the Baltic showing rapid decreases in pH. Automatic pH monitoring systems should be installed in ferryboxes if their long term stability can be guaranteed.

An indicator of societal pressure on the marine ecosystem is the frequency of oil spills. It is suggested that an oil spill (hydrocarbon) detector be included on the Bornholm Basin Buoy, lying as it does close to the principle ship route between the oil terminals of St. Petersburg and the entrance to the Baltic.

A summary of chemical indicators is presented in Table 7:

6.2.4 Biological indicators

In many respects, biological indicators are the most important state indicators. They demonstrate that the ecosystem is functioning as it should, which is the aim of, for example, the Water Framework Directive. Biological indicator development has been hampered by the labour-intensive analysis methods used. With the advent of automatic sampling systems, and the development of robust ocean colour algorithms, it is to be hoped that more robust indicators can be derived.

The fundamental biological indicators concern primary productivity. The spring bloom is fundamental, and is of great importance in the development of higher trophic levels. The bloom needs to be monitored with high frequency methods, to determine the timing of the start and peak of the bloom, as well as its length. Estimates of the production can be made using the oxygen anomaly method described in 7.2.3, or by using novel instrumentation such as Fast Repetition Rate Fluorimeters or Flourescence Induction and Relaxation Systems – although experience with these instruments in Sweden is limited. It is hoped that experience in these systems may be obtained through cooperation within ICES.

Maximum pCO2 depletion may also be used to determine primary productivity. Phytoplankton community structure is also important, with it responding to changes in the physical and chemical environment. Suitable indicators are the ratio of dinoflagellates to total plankton, and the ratio of diatoms to total plankton. Phytoplankton biomass is also relevant, and may be measured using calibrated chlorophyll-a fluorescence (typically from ferrybox systems) but also from biovolume estimates (manual counts from water samples, or from pump through optical counting systems). The successful establishment of new species is also an indication of change in ecosystem function.

Similar parameters are of interest to characterise summer, autumn and winter blooms, while monthly and annual primary production is of interest. During summer, cyanobacteria increase in importance, and the ratio of cyanobacteria to total plankton biomass may be used as an indicator. Cyanobacteria biomass may be determined by phycocyanin fluorescence, on buoys and ferrybox system.

OSPAR use the growing season mean chlorophyll a concentration as an indicator of phytoplankton biomass. Norwegian studies suggest that a sampling frequency of at least every three days is necessary to deliver this parameter reliably.

Acidification impacts calcareous phytoplankton directly. Lower pH results in more energy being required to maintain the plankton structure. Coccolithophorid cell number and species composition, as well as the bloom frequency and extent can indicate changes in acidification. In the Kattegat and Skagerrak, satellite images have been successfully used to identify coccolithophore blooms, although they have not been analysed quantitatively. More information on the carbonate system, both in surface and deep waters, can be obtained through studies of two or, ideally, three parameters: pH, alkalinity and pCO_2.

Harmful algal blooms (HAB) are thought to occur more frequently in eutrophicated systems, and in any case have direct economic consequences. The OSPAR Common Procedure requires the reporting of HAB events, and three indicators are proposed: the number of fish mortality, toxic shellfish and human illness events. In addition, the biomass of Nodularia Spumigena, and the extent of summer cyanobacteria blooms can be estimated by combining satellite and, for example, ferrybox or research vessel observations.

6.2.4 New indicators based on satellite products and suggested development

Phytoplankton biomass estimates using satellite products are discussed in chapter 3.6. A conclusion is that satellite products can be used in combination with in situ observations to produce estimates of phytoplankton biomass, timing and extent of spring bloom. The combination of satellite and in situ data can extend the point and line measurements (i.e.station and ferrybox data) to larger areas, whereas a number of satellite images covering the same area can be combined to a composite over a particular time period. The total phytoplankton biomass can be determined within a sea area or within specific geographic regions (boxes of e.g. 10*10 km) or from regions/water types defined from other criteria.

For the Skagerrak-Kattegat the chlorophyll a and total suspended matter algorithms are reasonably well validated (cf. chapter 3.6.3). However, clouds are frequently limiting the satellite data time resolution of surface water constituents. We therefore suggest that biomass maps on a weekly to monthly basis are produced from satellite products, using in situ FerryBox data to evaluate the satellite product quality in terms of an error analysis.

High temporal resolution data from ferrybox systems can be used to observe bloom evolution, especially the spring bloom, both in strength and in extent. Research vessel monitoring provides low time but high vertical resolution, high quality and all-embracing data sets for calibration and validation of both ferry box and satellite based products. In this way a set of new indicators can be obtained, covering spring blooms as a response to the winter nutrient pool, which can complement or even overrule the presently used indicators on summer biomass content showing low response to eutrophication.

In the Skagerrak-Kattegat satellite data can also be used to estimate the extent and the duration of coccolithophorid blooms as a long term indicator of changes in the carbonate system. This indicator can be based on the same methods as developed and used for summer cyanobacterial blooms in the Baltic Sea, which is SMHI:s deliverable to HELCOM (http://www.helcom.fi/environment2/ifs/ifs2008/en_GB/cyanobacteriaBlooms/).

In the Baltic Sea biomass algorithms needs to be adapted to the high concentrations of coloured dissolved organic matter (i.e. yellow substance). Presently the European Commission Joint Research Centre/Institute for Environment and Sustainability at ISPRA (http://ies.jrc.ec.europa.eu/marine-eutrophication) provides monthly based Indicators to HELCOM using a Baltic Sea adapted algorithm. Several ferrybox systems are available since many years in the Baltic Sea but so far the integration of the satellite based and in situ data are not made operationally.

7 INCORPORATING FERRYBOX SYSTEMS IN SWEDISH NATIONAL AND REGIONAL MARINE ENVIRONMENTAL MONITORING

A map of existing and proposed FerryBox routes is found in figure 68. When choosing routes the likelihood of long term operation by the shipping/ferry companies has been a priority.

7.1 Research vessels

A FerryBox system already exists on R/V Argos. It should be further developed and used for testing new sensors etc. An advantage with Argos is that a laboratory exist on the ship and highly qualified personnel can make reference measurements etc. A disadvantage with the ship is that it does not have a frequent fixed route like e.g. a ferry. Also some of the Ferries with FerryBox installations (e.g. Oslo-Kiel) are equipped with laboratory space where laboratory personnel can work.

7.2 New routes

7.2.1 Gothenburg-Uleåborg-Kemi-Lübeck-Gothenburg

A FerryBox system is being installed on the ship at present as a co-operation between SMHI and FIMR It is planned to be operational in summer 2009. The route is weekly. This route should be of interest also for Swedish regional monitoring, i.e. in the archipelago near Gothenburg with a possibility for frequent sampling at low cost.

7.2.2 Varberg-Grenå

A FerryBox system should be installed on a ferry on this route as described elsewhere in the publication. Stena Line AB operates the line and since Varberg is less than one hours drive from Gothenburg it would be convenient for the SMHI oceanographic laboratory to maintain a FerryBox system.

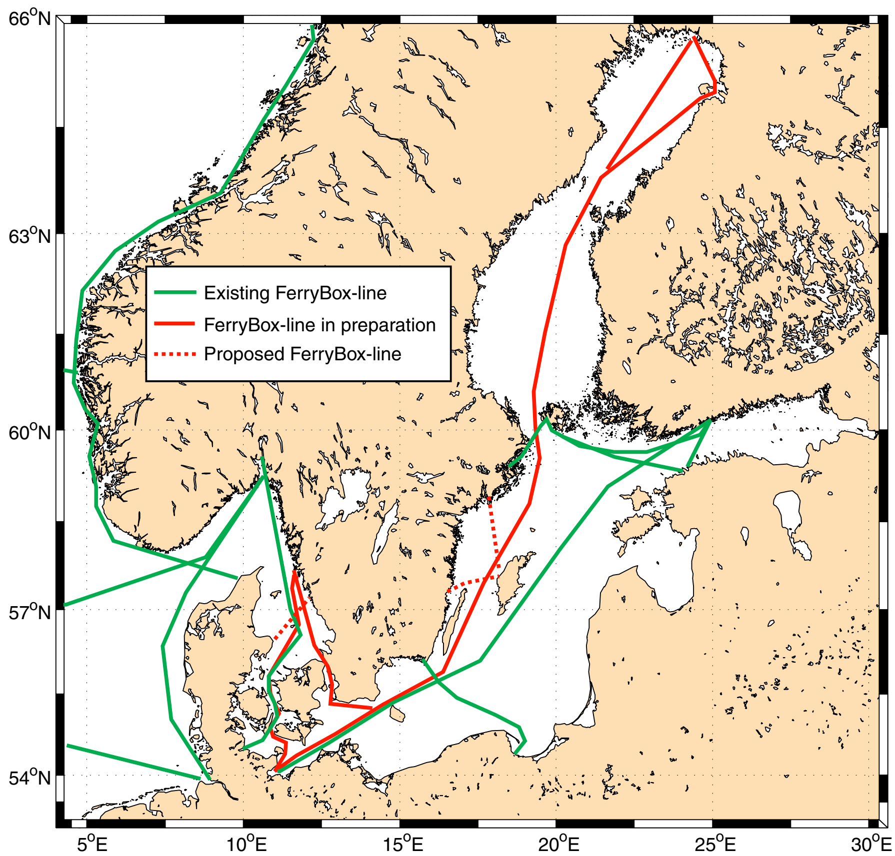


Figure 68. A. FerryBox routes in the Baltic Sea, the Kattegat, the Skagerrak, the eastern North Sea and the Norwegian Sea.

7.2.3 Nynäshamn-Visby or Oskarshamn-Visby

A FerryBox system should be installed on a ferry on at least one of these routes. Nynäshamn is accessible from the University of Stockholm and Oskarshamn is accessible from the University of Kalmar. A laboratory connected to the Swedish Institute for the Marine Environment (Havsmiljöinstitutet) in one of these locations could maintain the FerryBox system, analyse reference samples etc.

7.3 Existing routes

7.3.1 Helsingfors-Lübeck

FIMR operates a FerryBox system on the ferry Finnmaid on this route. The route has been used for FerryBox systems for fifteen years (Rantajärvi (2002) and the data produced has been very useful for HELCOM. SMHI and FIMR has started discussion about data sharing in near real time.

7.3.2 Oslo-Kiel

The Norwegian Institute for Water Research (NIVA) operates a FerryBox system on the ferry Color Fantasy. A co-operation with NIVA should be established for sampling in the Swedish part of the Skagerrak and the Kattegat and for real time data sharing. A detailed discussion between SMHI and NIVA (Kai Sørensen) about how to implement this is underway.

7.3.3 Bergen-Stavanger-Hirtshals

The Norwgian Institute for Water Research (NIVA) operates a FerryBox system on the ferry Bergensfjord. Real time data from the eastern North Sea – western Skagerrak would be very important as boundary conditions for the Baltic Sea physical and biogeochemical models being run operationally by SMHI. A co-operation between SMHI and NIVA should be established for sharing real time data. A discussion between SMHI and NIVA (Kai Sørensen) about how to implement this is underway. Also weekly samples of plankton and nutrients etc. in the Jutland current near the Danish coast would be of great interest.

7.3.4 Karlskrona-Gdynia

A FerryBox financed by the Baltic Sea Regional Project (Global Environmental Fund - World Bank) is operated by the the Institute of Meteorology and Water Management, Gdynia, Poland. SMHI has aided during the installation phase and also installed a real time communication system on the ferry Stena Nordica. The ship has now been moved to the Irish Sea and the FerryBox system has been removed. The plan is to install an improved version on another ship on the same route, the Stena Baltica A discussion between SMHI and IMWM (Włodzimierz Krzyminski) about further co-operation is underway. Water sampling in Swedish water is a priority for Sweden. This route should be of interest also to swedish regional monitoring, i.e. in the archipelago near Karlskrona with a possibility for frequent sampling at low cost. A laboratory in e.g. Kalmar could analyse the samples from Swedish waters.

7.3.5 Tallinn-Mariehamn-Stockholm

The Estonian Marine Institute operates a FerryBox system on the ship M/S Romantika on this route. The system will be moved to M/S Victoria in spring 2009. Water sampling is in the Tallinn Bay, the Western Gulf of Finland, the Northern Baltic Proper and in the outer Stockholm archipelago. SMHI and EMI (Andres Jaanus) has started initial discussion about co-operation. This route should be of interest also for Swedish Regional monitoring, i.e. in the Archipelago of Stockholm with a possibility for frequent sampling at low cost.

7.3.6 Helsinki-Mariehamn-Stockholm

FIMR operates a FerryBox system on the ship M/S Silja Serenade on this route. SMHI and FIMR has started discussion about co-operation. This route should be of interest also for Swedish Regional monitoring, i.e. in the archipelago of Stockholm with a possibility for frequent sampling at low cost.

7.4 Recommendations regarding methodology for cleaning system etc.

Weekly cleaning and visits onboard in combination with some automatic cleaning of the FerryBox system is recommended

7.5 Requirements for FerryBox systems

7.5.1 Basic parameters and equipment

- GPS (for determination of position)
- Water inlet and outlet separate from other in- and outlets on the ship, depth 4-5 m
- Pump that does not damage the sample
- Debubbler
- Temperature sensor at water inlet
- Thermosalinograph
- Chlorophyll a fluorometer
- Phycocyanin fluorometer
- Turbidity sensor
- Oxygen sensor
- Water sampling device (refrigerated, e.g. 24 one litre flasks)
- In air sensor for irradiance (PAR= Photosynthetic Active Radiation)
- Computer or advanced data logger for control of system

7.5.2 Additional parameters and equipment

- Water sampling device for phytoplankton samples (flasks pre filled with preservatives)
- Phycoerythrin fluorometer
- CDOM fluorometer
- Oil product fluorometer
- Nutrient analyser
- Phytoplankton analyser (in the future Imaging FlowCytobot or similar)
- pCO_2
- pH
- In air sensors

o Optical sensors for reference measurements for satellites
o Air pressure
o Humidity
o Wind speed and direction
o Sea Surface Temperature – skin sensor

7.5.3 Sampling frequency

Preferred sampling frequency for the automated measurements is every 20 seconds. Sampling every minute is also sufficient. Automated nutrient analysis and in the future phytoplankton analysis is possible e.g. every 15 minutes which means about every five nautical miles assuming a ship speed of 20 knots.

7.5.4 Data communication

The minimal transfer interval is every hour which means that 60-180 data sets are transferred every time. More frequent data transfer, e.g. every 15 minutes, is preferred. If data is transferred less frequently, e.g. every time the ship reaches port, the data will be much less useful for data assimilation into models etc.

8 INCORPORATION OF STATIONARY MEASUREMENT PLATFORMS IN SWEDISH MARINE ENVIRONMENTAL MONITORING

8.1 The climate and long term ecological research station concept

The main purpose of a long term station is to build a long-term oceanographic data set to be able to discern seasonal from long-term variability of hydrographic and biogeochemical parameters. Climate change and eutrophication are the main issues at present but the idea with long term stations is to monitor for the unexpected. To use the best practices available in long term ecological research goes without saying. There are at least three good examples where water sampling and measurements from research vessels are combined with measurements using buoys (moorings). These are the Bermuda Atlantic Time Series (BATS), Hawaii Ocean Time Series (HOT) and the European Station for Time-series in the Ocean, Canary Islands' (ESTOC). Especially BATS and HOT have provided invaluable data on the effects of climate change in the sea.

In the Baltic and the Kattegat-Skagerrak relatively long time series do exist for a few stations but sampling is infrequent and the new knowledge of the marine ecosystem is not fully utilized when designing the monitoring program. New techniques such as new optical sensors and molecular biology are not utilized. We propose that seven existing stations are designated as climate and long term ecological research stations. These stations should be part of an international network and contribute specifically to the EU Marine Strategy Framework, HELCOM and OSPAR monitoring. Relatively advanced moorings should be deployed at these locations and the investigations made from research vessels should be at the highest level possible. A possibility is that the work would be funded in part from the monitoring budget and in part from scientific funding. Long term commitments for funding are essential for the success of the concept.

8.2 Locations

The proposed stationary measurement platforms are for the following main purposes that in part overlap:

- Coastal monitoring – EU Water Framework Directive and climate and long term ecological research
- Off shore international monitoring – EU Marine Strategy Framework Directive and climate and long term ecological research
- National monitoring for specific purposes, i.e. data assimilation to models
- National parks and other marine protected areas
- Specific goals – e.g. harbour safety, wind mill parks, nuclear power plants, oil refineries and other chemical industries etc.

8.2.1 Off shore international climate and long term ecological research stations

Fulfilment of the Marine Strategy Framework Directive is one reason to deploy these moorings other reasons include long term ecological research, data assimilation into models and real time monitoring of conditions for warnings regarding marine safety, oil spills and algal blooms. Altogether seven locations are proposed for deployment of instrumented moorings with depth profiling instrumented platforms.

Bothnian Sea climate and long term ecological research station
The existing station C3 is selected. Water depth is c. 201 m. Position of mooring should be near the water sampling station at N62° 39.17’ E018° 57.14’.

Northern Baltic Proper climate and long term ecological research station
The existing station BY31 Landsort Deep is selected. Water depth is c. 459 m. Position of mooring should be near the water sampling station at N58° 35.0’ E018° 14.0’.

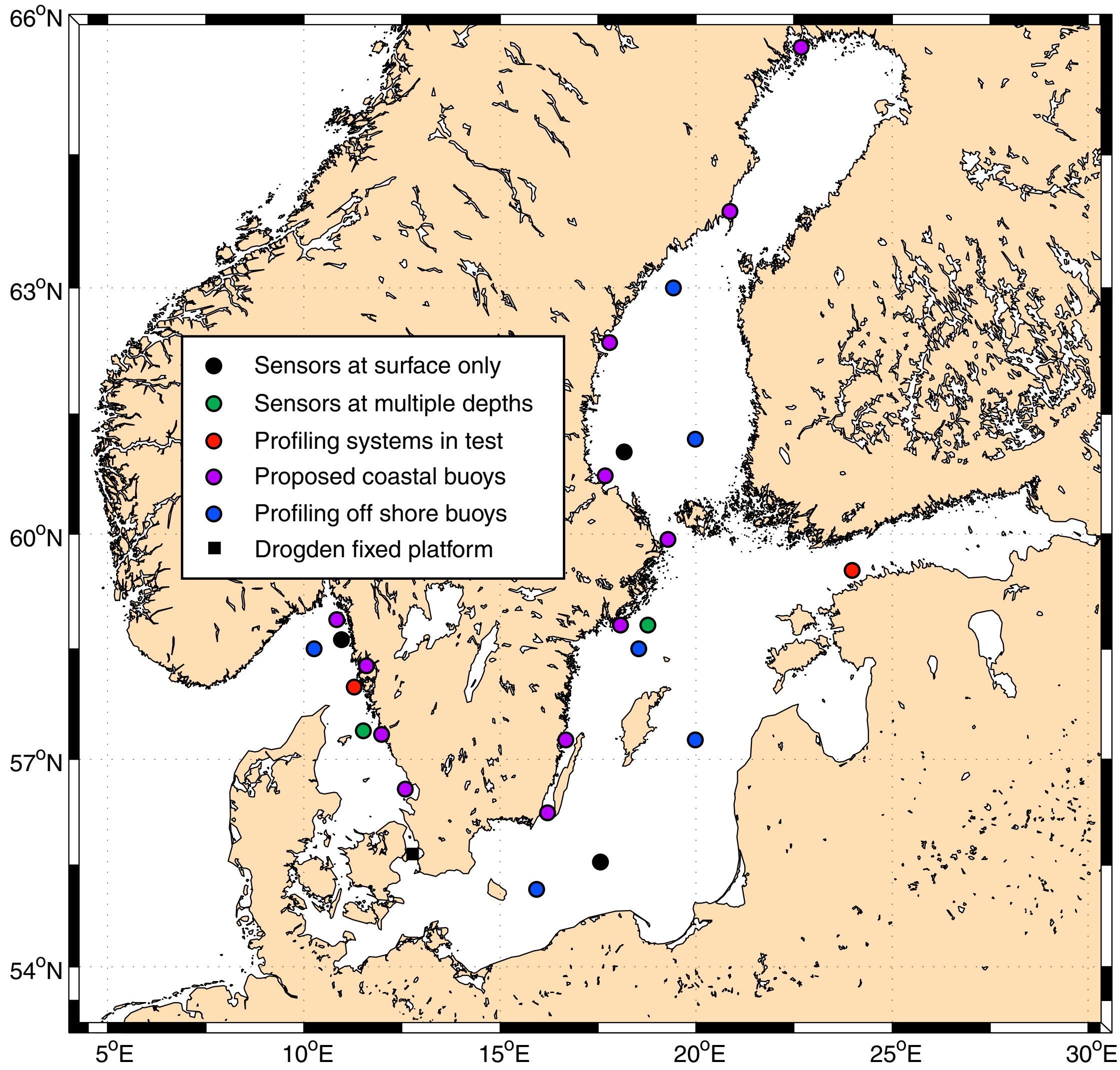


Fig. 69. Map showing the approximate locations of existing and proposed Swedish instrumented moorings and the Estonian profiling mooring off Tallinn. The black and green markers represent existing systems and the red ones are being tested. The remaining are new systems. It is suggested that the existing moorings Läsö E. and Huvudskär E. are moved to positions more suitable for marine monitoring purpsoses at stations where reference samples are collected regularly. The Läsö E. mooring would be moved south to a location near the Anholt E. station. The Huvudskär E. mooring should be moved to a location near the station BY31 Landsort deep.

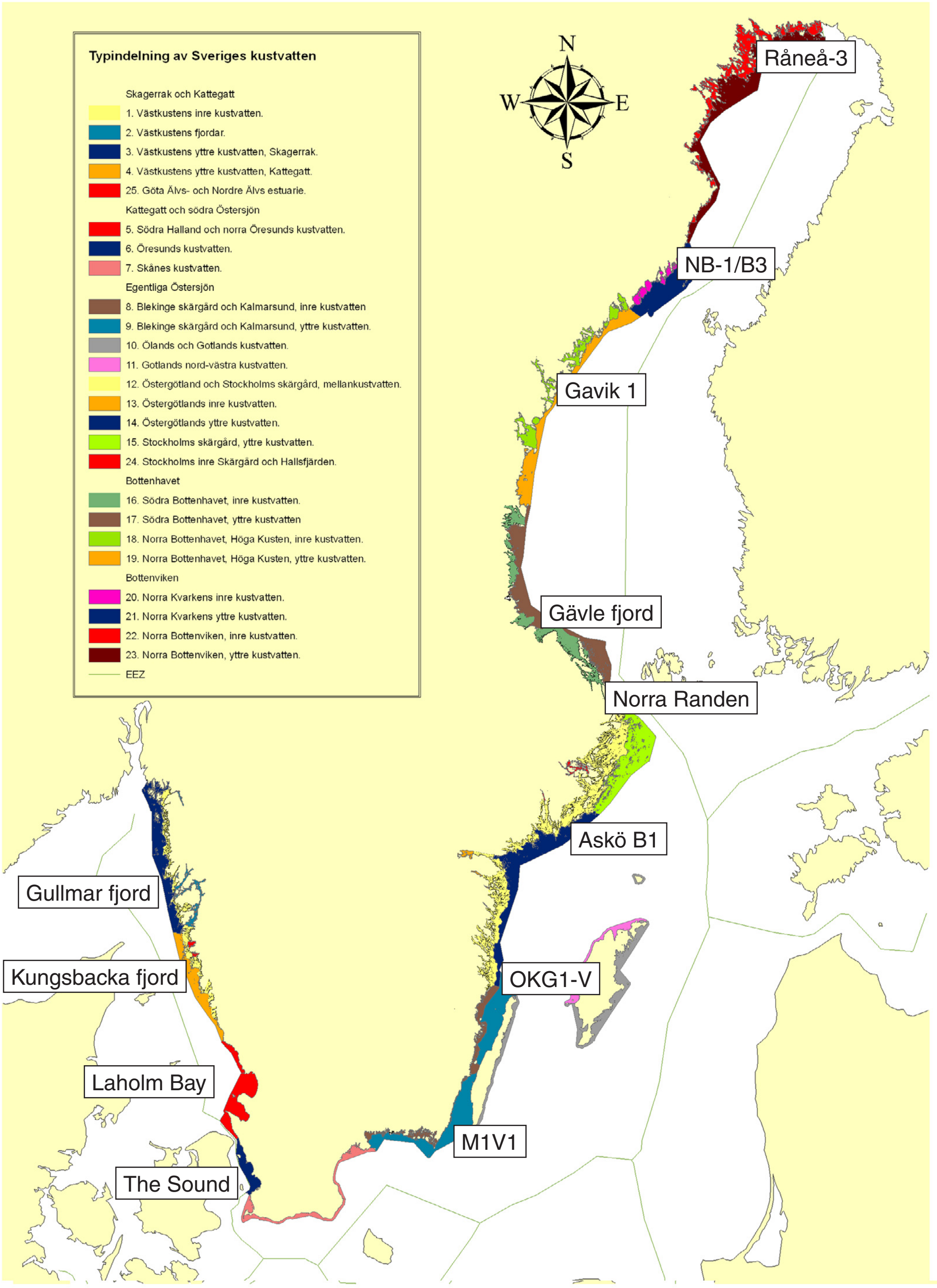


Fig. 70. Map showing the proposed coastal instrumented moorings in relation to the different water types around the coasts of Sweden. In the long term more systems should be added to cover all the water types in the seas surrounding Sweden. Measurement systems for specific monitoring purposes, e.g. ports, chemical industry, national parks, wind mill parks etc. are not included on the map.

Central Baltic Proper climate and long term ecological research station

The existing station BY15 Gotland Deep is selected. Water depth is c. 249 m. Position of mooring should be near the water sampling station at N57° 20.0' E20° 3.0'. This station is of particular importance due to the traffic of oil tankers.

Southern Baltic Proper climate and long term ecological research station

The existing station BY5 Bornholm Deep is selected. Water depth is c. 91 m. Position of mooring should be near the water sampling station at N55° 15.0' E015° 59.0'. This station is of particular importance due to the traffic of oil tankers and for the inflow of water into the deep basins in the Baltic proper.

Kattegat climate and long term ecological research station

The existing station Anholt E is selected. Water depth is c. 55 m. Position of mooring should be near the water sampling station at N56° 40.0' E012° 07.0'.

Baltic current climate and long term ecological research station

The location for the established buoy Måseskär W in the eastern Skagerrak is selected. Water depth is c. 50 m. Position of mooring is N58° 3.5' E11° 17.2'.

Central Skagerrak climate and long term ecological research station

The existing station Å17 in the central Skagerrak is selected. Water depth is c. 340 m. Position of mooring should be near the water sampling station at N58° 16.5 E010° 30.8'.

8.2.2 Coastal stations for WFD monitoring

Altogether twelve locations are proposed for initial deployment of instrumented moorings with depth profiling instrument platforms. The use of the data is mainly for the Water Framework Directive. There are two stations proposed in each of the five water districts in Sweden except for the Kattegat-Skagerrak district (Västerhavets vattendistrikt) where four stations are proposed. The number of moorings is of course a decision to be made by the regional authorities. The exact locations of moorings depend on conditions such as shipping routes, trawling restrictions etc. In a second stage more locations would be chosen to eventually cover all the 23 water types in the coastal waters surrounding Sweden.

8.2.1.1 Coastal stations in the Bothnian bay water district (Norrbotten - Bottenvikens vattendistrikt)

Water type Norra Bottenvikens inre kustvatten

Location: Station Råneå-3 (RA-3), position N65° 38.2 E022° 34.4, water depth c. 18 m.

Rationale The station is already part of a long term monitoring programme.

Water type Norra kvarkens inre kustvatten

Location: Station NB-1/B3, 63° 29.98' E019° 49.14', water depth c. 25 m.

Rationale The station is already part of a long term monitoring programme and is situated near the laboratory for the Umeå Marine Research Centre in Norrbyn.

8.2.1.2 Coastal stations in the Bothnian Sea water district (Västernorrland - Bottenhavets vattendistrikt)

Water type Norra Bottenhavet, Höga kusten, inre kustvatten

Location Station Gavik-1, position N62° 51.82' E018° 15.83', water depth c. 85 m.

Rationale The station is part of the long term monitoring programme in the area.

Water type Södra Bottenhavet, inre kustvatten

Location A station in the Gävle fjord, e.g. station K627, position N60°42.69' E017° 16.47'

Rationale The station is part of the long term monitoring programme in the area.

8.2.1.3 Coastal stations in the Northern Baltic Sea water district (Norra Östersjöns vattendistrikt)

Water type: Stockholms skärgård, yttre kustvatten

Location Station Norra Randen, position N60° 06' E18° 57', water depth c. 125 m.

Rationale The station is part of the long term monitoring programme in the area.

Water type: Östergötlands yttre kustvatten
Location: Station B1, position N58° 48' E17° 37', water depth c. 42 m.
Rationale The station is part of the national long term monitoring programme and the location is convenient to access from the Askö laboratory in the southern archipelago of Stockholm.

8.2.1.4 Coastal stations in the Southern Baltic Proper Water district (Kalmar - Södra Östersjöns vattendistrikt)

Water type Ölands och Gotlands kustvatten
Location Station OKG1-V, position N57° 24.55' E016° 41.7', depth c. 18 m.
Rationale The station is part of the long term monitoring programme in the area and situated near a nuclear power plant.

Water type Blekinge skärgård och Kalmarsund, yttre kustvatten
Location Station M1V1, position N56° 22.25' E016° 12.1', water depth c. 21 m.
Rationale The station is part of the long term monitoring programme in the area and situated near Kalmar University.

Water type Öresunds kustvatten
Location not defined.

8.2.1.5 Coastal stations in the Kattegat-Skagerrak water district (Västra Götaland - Västerhavets vattendistrikt)

Water type Södra Halland och norra Öresunds kustvatten
Location Station L9 in the Laholm bay, position N56° 33.90' E012° 43.20', water depth c. 20 m.
Rationale The bay is susceptible to anoxia due both to eutrophication and to the physical conditions, i.e. water depth is a few meters more than the depth of the pycnocline resulting in a small water volume where degradation of organic material occur. The station is part of the long term monitoring programme in the area.

Water type Västkustens inre kustvatten
Location Station N6 in the Kungsbacka fjord, position N57° 21.60' E012° 01.75', water depth c. 27 m.
Rationale The station is part of the long term monitoring programme in the area. There are plans for validating the results from a coupled biogeochemical model PROBE-SCOBI in this area. High resolution data would be very valuable.

Water type Västkustens fjordar
Location Station Alsbäck in the Gullmar fjord, position N58° 19.4' E011°32.8', water depth c. 119 m.
Rationale The station is part of the long term monitoring programme in the area. It is located conveniently for work from Kristineberg Marine Research Station in Fiskebäckskil.

8.2.3 Other national stations

Southern Bothnian Sea mooring for physical parameters
Station SR5/C4 is selected for measurement of profiles of salinity and temperature for data assimilation into models and for observations of the current physical oceanographic state.

Finngrundet mooring for physical parameters
The existing mooring measuring wave height and direction plus surface water temperature should be maintained and further developed.

Hanö bay mooring for physical parameters
Station Hanöbukten is selected for measurement of profiles of salinity and temperature for data assimilation into models and for observations of the current physical oceanographic state. Upwelling is of special interest here.

Drogden in the Sound (Öresund)
An automated observation system has been in operation at Drogden until a few years ago. Since the flow through the Sound is important for the Baltic and also for other reasons the measurements should be resumed.

Väderöbod mooring for physical parameters
The existing mooring measuring wave height and direction plus surface water temperature should be maintained and further developed.

8.3 National parks and other marine protected areas

The requirements for monitoring in marine protected areas may be higher compared to other areas. Kosterhavets nationalpark, Sweden's first marine national park will be inaugurated on 9 September 2009. The Koster fjord is probably the marine area with the highest biodiversity in Sweden. The fjord contains deep water species that are not found elsewhere in Sweden. Changes in climate and other environmental conditions may influence the area substantially. There are good reasons to establish a mooring in the fjord with a profiling platform with sensors for physical and biological parameters. Presentations of the conditions in the fjord will be part of the experience for visitors to the national park. Other protected marine areas in Sweden should be monitored in a similar way.

8.3.1 Stationary observation platforms for specific purposes

Specific sites often require specific solutions regarding observation systems. One example is the shipping route leading to a port where the most relevant parameters for maritime safety may be current speed and direction to secure that ships do not run aground. In the vicinity of nuclear plant the monitoring of in and out flowing cooling water and the effects of the surrounding area may be the key and chemical industries may need to monitor water transport in case of leaks etc. In wind mill parks monitoring the marine environment together with wind conditions is of main interest. One important point to make is that the base parameters described in 8.4.1 and 8.4.2 always should be measured to ensure that the exchange of data between different data providers will be fruitful.

Nuclear plant moorings
Forsmark
Barsebäck(?)
Oskarshamn
Ringhals

Refineries and chemical industry
Brofjorden – Scanraff refinery mooring
Stenungsund chemical industry mooring
etc.

Ports
Gothenburg
Malmö
Kalmar
Stockholm
Umeå
etc.

Wind park piles
In off shore wind parks piles are often suitable to monitor the near surface water and also to measure wind and other relevant parameters for the power production. Here follows some areas where piles should be used as measurement platforms in existing or planned wind mill parks:

Skottarevet near Falkenberg
Stora Middelgrund in the Kattegatt
The Sound (Öresund)
Lilla Middelgrund
Kriegers flak south of Skåne
Hanö bay
Södra Midsjöbankarna southeast of the island of Öland
Bockstigen near Näsudden South western Gotland
Southern Kalmarsund
Yttre Stengrund
Utgrunden
Trolleboda near Utgrunden
Finngrundet in the Gulf of Gävle

8.4 Parameters, temporal and vertical resolution

8.4.1 About sampling frequency

The desired sampling frequency for instrumented moorings is every hour but also every three hours is acceptable.

8.4.2 Basic requirements

In air sensors

- Air temperature
- Irradiation. PAR (standard on piles, optional on buoys)

In water sensors at 1 m depth

- Water temperature

- Salinity
- Phytoplankton biomass - chlorophyll a fluorescence
- Biomass of cyanobacteria – phycocyanin fluorescence (not needed in the Skagerrak)
- Turbidity

In water sensor near sea floor

- Water temperature
- Salinity
- Oxygen
- Turbidity

8.4.3 Requirements for long term climate and ecological research

The requirements are the same as for the basic requirements with the following additions

In air sensors

- Irradiation sensors (PAR 400-700 nm)
- Air pressure
- Wind speed and direction
- In water sensors at 1 m depth
- Detectors for inorganic nutrients
- Detector for hydrocarbons (oil)

In water sensors on profiling platform (depth resolution should be better than 0.5 m)

- Water temperature
- Salinity
- Phytoplankton biomass – chlorophyll a fluorescence
- Biomass of cyanobacteria – phycocyanin fluorescence
- Inorganic nutrients
- Oxygen
- Turbidity
- CDOM (humic substances)
- Irradiance (PAR)

8.4.4 Specific requirements in some locations

- Current speed and direction measured using an ADCP e.g. in the Sound (Öresund) and near ports.
- Wave height and direction is to be measured at a selectet number of locations, e.g. one in each of the main sea areas.

8.5 Maintenance and service intervals

Instruments must be fitted with appropriate anti fouling devices. It is likely that service interval will be 2-3 months depending on location and time of year. Bio fouling is faster in the Kattegat-Skagerrak compared to the Baltic Sea. The ideal situation is that a number of identical instrumented moorings are used in different locations. This means the logistics for service, calibration of instruments etc. can be efficient. Complete systems are replaced at sea while service is performed on land. This keeps ship costs down and ensures a high data retrieval.

8.6 Water sampling and reference measurements

Regular sampling near the automated observation systems is a requirement to guarantee data quality. The manual for marine environmental monitoring produced by the Swedish Environmental Protection Agency is the base for sampling and analyses techniques (in Swedish Undersökningstyper, programområde Kust och Hav). It may need updating for some of the parameters discussed in this report.

8.7 Web links for chapter eight

European Station for Time-series in the Ocean, Canary Islands' (ESTOC)
http://iodp.de/ESTOC_European_Station_for_Time_series_in_the_Ocean_Canary_Islands.html

Bermuda Atlantic Time-series Study (BATS)
http://bats.bios.edu/

Hawaii Ocean Times Series (HOT)
http://hahana.soest.hawaii.edu/hot/hot_jgofs.html

9 ORGANISATION AND LOGISTICS

The initial cost of an automated ocean observing system is only part of the total cost. Maintenance, calibration of instruments, reference sampling and analyses of samples and data management and presentation are actually the major part of the total cost if a period of ten years is considered. The lifetime of buoys, instruments and FerryBox-systems may be expected to be 6-10 years. To purchase observation systems, inviting tenders etc. is also a time consuming task that requires special expertise. A conclusion is that it would be an advantage if several stakeholders join in partnerships to buy, operate and maintain observation systems. Here follows a suggestion for Sweden.

9.1 FerryBox-systems

Collaboration with other countries and institutes in the Baltic-Kattegat-Skagerrak area is important and may be promoted e.g. through HELCOM, OSPAR and the EU. The Swedish systems should be national and purchased and owned by one institute, e.g. SMHI. The council for the newly formed Swedish Institute for the Marine Environment (Havsmiljöinstitutet) is the natural body for co-operation within Sweden. Funding may come from e.g. the National Environmental Protection Agency. Financing analyses of samples near the coast may be the responsibility of regional authorities while analyses of off shore samples is the responsibility of the Environmental Protection Agency. The weekly maintenance and collection of water samples should be performed by partners that have an oceanographic laboratory within 1-2 hours drive from the port of the ship with the FerryBox. For the proposed lines in this report this means e.g. the SMHI laboratory in Gothenburg, laboratories at the universities of Kalmar and Stockholm, NIVA, FIMR, IMWM and EMI. Funding for operation of FerryBox systems may be both national and regional.

9.2 Instrumented moorings and piles

A partnership for coastal systems aimed at producing data for the Water Framework Directive should be formed. The Water districts could have a leading role in the partnership and water quality associations, ports, nuclear power plants etc. could join. The operation of moorings and piles should be performed by partners that have access to ships near the locations of the systems. This will often be a partner that also collects water samples regularly.

The off shore moorings should be operated by a partnership of the SMHI, the Swedish Institute for the Marine Environment (Havsmiljöinstitutet), the Swedish Board of Fisheries, the Swedish Coast Guard, the Swedish Maritime Administration (Sjöfartsverket) and the Swedish Navy. SMHI is proposed to be the lead partner. Co-operation with other countries through HELCOM and OSPAR is of course important.

A central unit for maintaining the systems, calibrating instruments etc. should be established. SMHI:s oceanographic buoy maintenance unit and the oceanographic laboratory in Gothenburg is one alternative. A close co-operation with the Swedish Institute for the Marine Environment (Havsmiljöinstitutet) is important. Commercial actors may of course also establish maintenance units but since the commercial market is relatively small this is not very likely.

10 DATA MANAGEMENT

The following principles should guide data management for all data produced using automated techniques in marine environmental monitoring etc.

1. All data produced using automated observation systems such as FerryBox-systems and measurements using moorings and piles as platforms should be made freely available to society. Data providers may choose to set a delay for the public access to data of no more than one year.
2. Data should be made available within one hour after measurement.
3. Data reported within one hour after measurement is considered near real time.
4. A national data host for the oceanographic real time data shall be designated. We suggest that the Swedish National Oceanographic Data Centre at SMHI will have this function. Long term funding for the function is a requirement.
5. All data shall be reported to the national data host.
6. All data providers get access to other data in near real time.
7. The national data host make data available for other users, e.g. for warnings, assimilation into models etc.
8. The national data host provide basic data presentation on the Internet
9. The national data host provides a system for long term storage of quality controlled data and a way to make it available on the Internet.
10. Quality control and quality assurance are important issues
11. Data will be available with at least three levels of quality:

a. Near real time data with little or no quality control

b. Quality controlled data after analyses of reference samples

c. Highest level of quality data delivered yearly to e.g. ICES.

12. Reference measurements and calibrations of instruments are integrated parts of the system.

The data sharing systems at BOOS (Baltic Operational Oceanographic System) and NOOS (North West Shelf Operational Oceanographic System) will be the tools to share data between nations in near real time. ICES and IODE (The IOC's International Oceanographic Data and Information Exchange) are at present the platforms for exchange of quality controlled data. INSPIRE may provide an additional platform in the future. Information regarding meteorological parameters should also be made available through existing meterorological data sharing systems.

11 A VISION FOR A FUTURE INTEGRATED INTERNATIONAL OCEAN OBSERVATION SYSTEM FOR THE BALTIC AND THE KATTEGAT-SKAGERRAK

The proposed observation systems in this report should be part of a larger network. The framework of the UNESCO-IOC Global Ocean Observing System (GOOS) exists but needs to be further developed, especially regarding biological parameters. EuroGOOS is the European contribution to GOOS while BOOS and NOOS are regional organisations. The first issue is to integrate the systems in different countries around the Baltic and the countries around the North Sea-Skagerrak-Kattegat. Tools for data sharing exist in BOOS and NOOS but are not yet fully used and developed. Of special interest to Sweden are measurements in the eastern North Sea and the western Skagerrak. The conditions in this area represent boundary conditions for Baltic Sea models and the water transported with the Jutland current influences the Skagerrak and the Kattegat substantially.

Specific issues to address regarding measurements outside Swedish waters, i.e. international co-operation:

The Baltic

- Deployment of measurement platforms near the shipping route for petroleum products
- Swedish access to near real time data from the FerryBox lines operated by institutes in Finland, Estonia and Poland.
- Validation of satellite algorithms for determination of phytoplankton biomass as chlorophyll a for the Baltic Sea.

Skagerrak-Kattegat

- Deployment of at least one measurement platform in the Jutland current. Here at least two alternatives exist: a pile or a mooring. The platform should be situated in the vicinity of Hirtshals. An agreement with e.g. the Danish National Institute for Environmental Research should be made. An alternative solution is to use the FerryBox line Hirtshals-Stavanger-Bergen for sampling of surface water in the Jutland current. Here NIVA is one partner.
- Near real time access to data from the stations along the transect across the western Skagerrak, Torungen – Hirsthals. An agreement concerning delivery of near real time data with the Norwegian Institute for Marine Research should be made.
- Access to near real time data from FerryBox lines in the Kattegat and eastern Skagerrak on the Oslo-Kiel route. Also nutrients, chlorophyll-a and phytoplankton data from water samples onboard should be made available. This line can be used for satellite product validation. An agreement with the Norwegian Institute for Water Research should be made.
- Access to near real time data from FerryBox lines in the eastern North Sea and the Skagerrak. An agreement with the Norwegian Institute for Water Research and the German institute GKSS should be made.

12 A STEPWISE PLAN ON IMPLEMENTING AUTOMATED MARINE PELAGIC MONITORING SYSTEMS IN SWEDEN

In this report the possibilities with the use of automated ocean observation systems in the monitoring the seas surrounding Sweden is presented. Also the problems with the systems have been shown. Our conclusion is that automated systems should be incorporated in the Swedish environmental monitoring stepwise. This is our proposed implementation plan for a new infrastructure for real time measurements.

Step 1. Establishment of a national data host for real time ocean observing systems

The near real time data and the water sample data should be collected in the same system to enable efficient data sharing and further reporting to EU, IOC, ICES, HELCOM and OSPAR. The data host should be the Swedish node for BOOS and NOOS. The National Oceanographic Data Centre at SMHI is proposed to be the national data host for real time ocean observing systems.

Step 2 Establishment of formal co-operation with other data providers

Formal agreements need to be signed with institutes in Finland (SYKE), Norway (IMR and NIVA), Denmark (NERI), Germany (IOW, GKSS), Poland (IMWM), Estonia (EMI, MSI), United Kingdom (SAHFOS - Continuous Plankton Recorder) and other data providers. A cost for specific sampling for Swedish requirements is to be expected.

Step 3. Establishment of the FerryBox-line Gothenburg-Uleåborg-Kemi-Lübeck-Göteborg

The reason to start with this is that the surface water of most sea areas around Sweden will be covered. The co-operation with FIMR/SYKE is essential for the success. The establishment is underway.

Step 4 Establishment of coastal buoy systems

Data produced will be used e.g. for the Water Framework Directive implementation. Initially stations with instrumented buoys should be established near the marine field stations in Sweden. The reason to work near the field stations of the Swedish Institute for the Marine Environment (Havsmiljöinstitutet) in Norrbyn, Askö, Kalmar, Kristineberg and Tjärnö is that it will be possible to efficiently use facilities such as ships and laboratories during a period when teething problems with automated systems will be solved. Also existing sampling programmes can be used for reference measurements at no or low extra cost Analyses of new parameters such as molecular and optical ones initially need to be measured in a scientific context. SMHI should play a central role as co-ordinator of the measurements and for maintenance and calibration of platforms and instruments. A disadvantage with coastal stations is that they often only represent a relatively restricted area.

Step 5 Establishment of off shore climate and long term ecological research stations

Data produced will be used e.g. for the EU Marine Strategy Framework Directive. These systems will produce high quality data representative for larger areas. The long term funding for the water sampling and analyses as well as the maintenance of the buoy systems are crucial.

Step 6. Establishment of routine monitoring of phytoplankton biomass and algal blooms using remote sensing

Monitoring of blooms of cyanobacteria is underway and blooms of coccolithophorids should be made on a routine basis as soon as funding is made available. In the Skagerrak and the Kattegat the available chlorophyll a algorithms should be evaluated during a test period. In the Baltic further development of algorithms for determination of surface chlorophyll a from satellite data is needed. CDOM meaurements as well as samples of chlorophyll a and phytoplankton analysis is important to achieve the goal.

Further steps Establishment of new FerryBox routes

The routes Varberg - Grenå and Oskarshamn - Visby or Nynäshamn - Visby should be established. It is essential that an accredited oceanographic laboratory is available for analyses of reference samples and maintenance of the systems.

13 DISCUSSION AND CONCLUSION

13.1 Why use a combination of different sampling platforms?

The sampling platforms described in this report all have advantages and disadvantages which are summarised in table 1. Sampling from research vessels provide the most detailed information and the highest quality of data since these ships are equipped with laboratories on board and storage time of samples is minimized. Adaptive sampling, e.g. collecting phytoplankton samples at the depth of maximum chlorophyll a fluorescence is possible. The disadvantage with research vessels is that the sampling frequency is usually low due to cost. FerryBox systems are very cost effective and facilitate both automated measurements and water sampling. A disadvantage is that only the near surface water is investigated. Instrumented buoys with depth profiling sensor platforms give frequent data from the whole water column at one location. They can also be used for water sampling but samples must be collected from buoys with ships. Satellites give a large horizontal cover of surface water but clouds often constitute a problem. If a combination of technologies are used a much better understanding of events will be achieved compared to if the systems are used separately. It should be emphasized that the waters surrounding Sweden are stratified most of the time due to lower salinity near surface and in summertime also due to temperature. This means that monitoring of surface water alone overlook processes deeper down, e.g. hypoxia, subsurface algal blooms etc.

There is, or at least has been, a contridiction between amount of detail in observations and the horisontal and vertical resolution. The methods that give the greatest detail also have the lowest temporal and spatial resolution and vice versa. In part this is changing since new optical and molecular techniques are being used in automated in situ systems. But one still has to weigh the advantages and disadvantages with the different methods when designing a monitoring programme. Most often pilot studies using high frequent sampling with detailed analyses must be carried out before realistic goals of a programme can be set. On the other hand monitoring is also about detecting unexpected changes which cannot be predicted or tested in pilot studies. The proposal of a system of satellites, FerryBoxes, buoys and research vessel sampling is based on experiences of the results obtained from the last decades of sampling. If it is implemented it should be evaluated after e.g. a period of ten years.

13.2 Evaluation of data from FerryBox systems

FerryBox parameters collected by the the Alg@line and NIVA systems are robust, in good agreement with quality assured observations from research vessels, and give a detailed representation of the surface waters of the Baltic Proper and the Kattegat-Skagerrak. Samples analysed from the water sampler also appear to be of good quality.

13.2.1 The Kattegat-Skagerrak

The most obvious observation about the results is that the high frequency sampling using the FerryBox systems makes it possible to reliably detect the spring bloom and other phytoplankton blooms. Traditional sampling from research vessels is simply too infrequent to detect the spring bloom most years. Nutrients were not compared but the concentrations vary as quickly as the phytoplankton blooms. Temperature measurements from the FerryBox system are consistent with the measurements made from research vessels. Correlation between FerryBox and research vessel salinity is more variable in the Skagerrak. This may be due to movement of fronts between different water masses in between the sampling from the ferry and the research vessel.

Chlorophyll a fluorescence is a good proxy for chlorophyll a although neither are a substitute for phytoplankton biomass determined using microscopy (Krupskoff and Flynn, 2006). The difference between extracted chlorophyll a analysed using a relatively simple fluorescence detector and a liquid chromatography system is to be expected. The latter system separates the other photosynthetic pigments from chlorophyll a before detection. Remote sensing of chlorophyll a seem to be quite useful in the Skagerrak. The comparison between FerryBox data and MERIS data yield quite impressive results.

13.2.2 The Baltic

Spatially, the direct measurements (temperature, salinity, chlorophyll fluorescence and turbidity) give very high resolution data. In the southern Baltic Proper, water sampler data does not give a much better spatial resolution than that obtained from research vessels, with only one sampling point each in the Arkona Basin, Hamrarne Sound and Bornholm Basin. Spatial resolution is better in the East Gotland Basin and western Gulf of Finland (as might be expected from a Finnish funded system).

Temporally, the resolution appears reasonable, with small scale changes in salinity along the German coast being seen to both grow and decline, rather than appearing as simple noise. The sampling frequency of the water sampler makes it difficult to see some sampling peaks which occur, for example, in the underway chlorophyll fluorescence signal.

Contrasting the data collected by Alg@line with "conventional" HELCOM sampling at BMP stations shows Alg@line to be a useful complement, but the water sampler data do not give a major temporal improvement over the conventional monitoring programme.

The high frequency high resolution data from Alg@line is most impressive. If nutrient data could be collected at a similar frequency, perhaps using an in-line autoanalyser such as the N-virotech AutoLab then the impact of biological patchiness on the nutrient field could be determined. An in-line autoanalyser would remove the problem of storing samples for up to 5 days, and would produce data at a similar spatial resolution to the current generation of ecosystem models. Water samples could then be used to provide "ground truthing" of the autoanalyser.

The automatic water sampler would make a significant improvement to existing underway data collected by U/F Argos. The water sampler could be programmed to take samples every quarter of an hour, giving a spatial resolution of about 2.5 nm along the ship's track. This would be just about adequate to resolve the first order Rossby radius in the Kattegat and Skagerrak, which is the physical length scale governing variability. Samples could be processed daily, using the AlpChem autoanalyser that is already in place. An in-line autoanalyser could improve this resolution further, and be ground truthed against the water samples taken during the conventional monitoring.

13.2.3 Conclusions about the evaluation of FerryBox systems

The Alg@line system has increased the volume of environmental data available from the Baltic Proper. The high frequency sampling of temperature, salinity and chlorophyll fluorescence captures both high frequency and small scale variability. The low frequency water samples provide useful information, but are not such a significant improvement that they could replace existing HELCOM monitoring activities. It should be remembered also that ferrybox systems can only monitor surface waters, and do not give any information on the oxygen or nutrient dynamics below the mixed layer.

The system could be improved with nutrient observations at a similar frequency/resolution to the automatic monitoring systems. Both automatic water samplers and in-line autoanalysers would be a significant improvement to the existing Swedish monitoring programme, allowing it to resolve surface nutrient variability, as well as describing changes through the water column.

Finally, the gaps and changes in sampling regime apparent in the Alg@line data make it apparent that it is not a "fit and forget" system. To produce high quality data requires resources, experience and the implementation of robust quality control routines. Ideally, such systems should be accredited in the same way as analysis laboratories, to guarantee the quality of data being produced.

FerryBoxes such as Alg@line and the NIVA system are an increasingly popular way of monitoring the marine environment, but should still be seen as a complement to "conventional" research vessel based monitoring – at least until a dense network of reliable data buoys is capable of providing profile data of equivalent quality.

13.3 Final thoughts

A combination of different measurement and sampling techniques using research vessels, instrumented moorings, Ferrybox-systems and remote sensing is proposed to monitor the marine environment in the seas surrounding Sweden. This is necessary to cover the spatial and temporal scales of the processes investigated. The initial cost of the automated observations systems proposed in this report is substantial and also the operation of the systems involve costs. However, we argue that the benefits for society are much higher than the cost. In short – the understanding achieved on what is happening in the Baltic and the Kattegat-Skagerrak will pay off in better management of the natural resources.

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ACRONYMS

Acronym	Description
ADCP	Accoustic Doppler Current Profiler
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BOOS	Baltic Operational Oceanographic System
CEFAS	Centre for Environment, Fisheries & Aquaculture Science, United Kingdom
Chl. a	Chlorophyll a
CTD	A device lowered from a ship measuring Conductivity, Temperature and Depth. Salinity is calculated and other sensors are usually also deployed.
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphous
EMI	Estonian Marine Institute, University of Tartu
EuroGOOS	The european part of the Global Ocean Observing System
ESA	European Space Center
FIMR	Finnish Institute for Marine Research
GKSS	GKSS, Institute for Coastal Research, Germany
GOOS	Global Ocean Observing System
HELCOM	Helsinki Commission
ICES	International Council for the Exploration of the Seas
IFREMER	
IMR	Institute for Marine Research = Havforskningsinstituttet, Norway
IMWM	The Institute of Meteorology and Water Management, Gdynia, Poland
INSPIRE	Infrastructure for Spatial Information in the European Community
IOC	The Intergovernmental Oceaographic Commission (UNESCO, United Nations)
IODE	The IOC's International Oceanographic Data and Information Exchange (IODE)
IOW	Institut für Ostseeforschung, Warnemünde, Germany
MERIS	MEdium Resolution Imaging Spectrometer
MODIS	MODerate resolution Imaging Spectroradiometer
NERI	National Environment Research Institute = Danmark Miljøundesøgelser at Århus Univeristy, Denmark.
NIVA	Norwegian Institute for Water Research
NOOS	North West Shelf Operational Oceanographic System
OSPAR	The Oslo Paris Commission
PRODEX	PROgramme de Dévelop-pement d'EXpériences scientifique (European Space Agency)
SAFHOS	Sira Alistair Hardy Foundation for Ocean Science, united Kingdom
SMHI	The Swedish Meteorological and Hydrological Insitute
SYKE	The Finnish Environment Agency
totN	total nitrogen, i.e. dissolved inorganic, organic and particlulate
totP	total phosphorous, i.e. dissolved inorganic, organic and particlulate
TRK	Transport Retention Source Apportionment (Transport Retention Källfördelning)
TSM	Total Suspended Matter

SMHI PUBLICATIONS

SMHI publishes six report series. Three of these, the R-series, are intended for international readers and are in most cases written in English. For the others the Swedish language is used.

Names of the Series	Published since
RMK (Report Meteorology och Climatology)	1974
RH (Report Hydrology)	1990
RO (Report Oceanography)	1986
METEOROLOGI	1985
HYDROLOGI	1985
OCEANOGRAFI	1985

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