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OPERATIONAL OCEANOGRAPHY OF THE NORTH SEA/SKAGERRAK AND NORWEGIAN SEA BY FERRBOX SYSTEMS: FROM ONE LINE TO A COORDINATED NETWORK OF FERRYBOXES

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The FerryBox project, supported by the EC has documented that Ferryboxes are mature systems for monitoring of water quality in coastal areas. A network of Ferryboxes has been established within the North Sea/Skagerrak and Norwegian Sea. Four ferries are at the moment in operation in these areas and new lines are planned. The network and results from observations will be presented. The results are available in real time for the core sensors temperature, salinity, particles and algal biomass measured as Chlorophyll-a fluorescence. The systems are also equipped with a water sampling system can be triggered remotely. This makes the system very operational for e.g. monitoring of harmful algal blooms.
New sensors and measurements of e.g. nutrients are considered based on the experience from the FerryBox project. In addition advanced measurement of water leaving reflectance is measured and is used for real time validation of optical satellite data. The Ferrybox results are compared with remote sensing data, in order to have a better knowledge of the spatial development and combined with numerical models to improve significance. The data from the Ferrybox sensors and satellite data are presented in a common portal to have easy access to all data and additional information.

KEYWORDS: Operational Oceanography, Ferrybox

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Introduction

Improving our coastal monitoring and mapping capability is a major task in order to meet present challenges such as the implementation of the EU water framework directive, the management of conflict areas or more generally the detection of reliable trend related to environmental changes.

The monitoring of Coastal water systems with their strong dynamic variability (e.g. Wiltshire and Dürselen, 2004; Reid and Edwards, 2001) requires a very dense sampling in time and space. The high resolution is necessary to assess the patchy nature of plankton blooms and high temporal variability caused e.g. by short term events like exceptionally strong phytoplankton blooms or upwelling events that may cause Harmful Algae Blooms (Kanoshina et al., 2003).

Actual programs on *in situ* monitoring are mainly carried out by manual sampling and subsequent analysis along with regularly (semi-annual or quarterly) monitoring cruises with

Research Vessels or by stationary measuring systems like buoys. Hence, they are lacking either, temporal or spatial resolution. Initiatives to overcome this limits are being tackled world-wide by the Global Ocean Observing System (GOOS) and in Europe by EUROGOOS. Comparable activities have been started within ICES. Key of those initiatives are the development of new methodologies, aiming in the combination of *in situ* observations, remote sensing, ship of opportunity observations (SOOP) and Numerical Modelling as a step forward in coastal monitoring providing added value from synthetisation of the different methods leading to an improved marine ecosystem understanding.

Specifically the usage of Ships of Opportunity (SOOP) was strongly recommended by EUROGOOS (Flemming et al., 2002), since they allow for cost effective monitoring with high resolution in space and time. SOOP measurements have a long tradition, starting with the continuous plankton recorder (Reid et al., 2002) and the long history on observations on the Hurtigruten (http://pegasus.nodc.no:8080/termograf/). More sophisticated measurement systems (Ferryboxes) that are able to measure a large set of oceanographic and biological parameter were recently further developed and applied within the EU-FerryBox project (Rantajärvi 2003; Swertz et al. 1999; Harashima and Kunugi 2000, Hydes et al. 2003, Petersen et al. 2003, Ridderinkhof et al. 1999, Petersen et al., 2006). An observational network of Ferryboxes has been established during the past five years. In Norwegian waters the activity in NIVA started with a Norwegian Research Council project in 2001 (Magnusson et al., 2003), which through EU-projects (FerryBox, DISMAR) and project for the European Space Agency (VAMP) and the Norwegian Space Centre (SatOCEAN) has considerably been extended. Additional lines, e.g. crossing the North Sea from Bergen to Newcastle and cruising from Oslo via Rotterdam to Hamburg (will be established in autumn 2006 in collaboration between GKSS Research Centre and NIVA), will provide very useful data concerning contaminant transport out of the Southern North Sea heading the Norwegian Coastal waters. With these Ferryboxes running, most of the Norwegian coastal areas can be monitored (Figure 1).

While running more or less the same track each transect the spatial and temporal resolution of observations is very high along the route of the Ferries. However, the temporal and spatial information aside the ferry route is only limited and the measurement is only done at one depth. Remote sensing techniques here provide additional information and synoptic estimates of several water quality parameters over horizontally widely spread and very remote areas are possible. First exemplary studies combining Ferrybox data with satellite remote sensing data allowed significantly improved reporting of ecosystem state (Pulliainen et al. 2004, Vepsäläinen et al. 2005, Petersen et al., 2006, Sørensen et al., 2006). However, similar to FerryBox observations, remote sensing is as well limited to the ocean surface. Moreover parameters derived from optical sensors (chlorophyll, suspended matter, yellow substance) can only be obtained when cloud conditions permit a free view of the satellite sight to the sea.

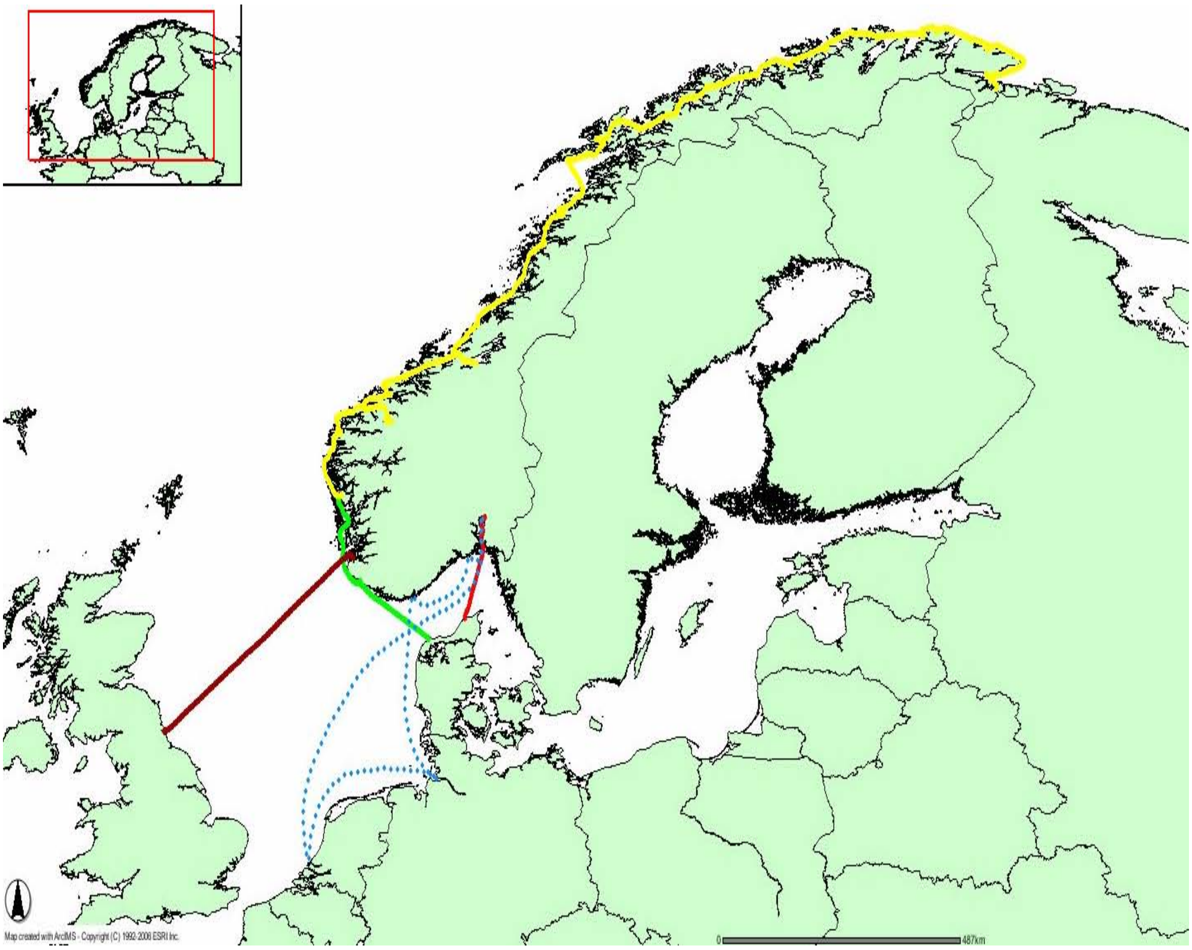

Figure 1: Course of Ferrybox lines (Solid lines = already established, dotted line = planned line, collaboration between GKSS and NIVA)

Ferrybox system network:

Detailed descriptions of Ferrybox systems are available at the homepage of the finalized EU-supported project FerryBox (refer to http://www.ferrybox.com). Generally the Ferrybox systems consist of sensors measuring the core parameters chlorophyll-a fluorescence, turbidity, temperature and salinity. Optional sensor for down-welling irradiance (PAR) is measured at top deck, nutrient analyses or other parameters like oxygen are connected to the systems. The systems have the possibilities to automatic collect water samples on fixed positions. The systems are fully automatic and controlled by the GPS signals (Waypoints). The sensors are controlled with the software LabView. Detailed information on the specific systems are, or in case of the triangle route will be available at the internet:

Hurtigruten line operated by NIVA : http://www.ferrybox.no
Hurtigruten line operated by IMR : http://pegasus.nodc.no:8080/termograf/
Skagerrak line operated by NIVA : http://www.ferrybox.no
Bergen-Newcastle line operated by NIVA : http://www.ferrybox.no

To ensure the acquisition of data with high quality, a regularly cleaning and supervision of the systems is necessary and is conducted by the operators. Detailed descriptions of the applied data quality assurance procedures are available on web at the FerryBox homepage (http://www.ferrybox.com). As an example Figure 2 displays the availability of quality assured data by means of the Skagerrak Ferrybox line for the years 2003 and 2004

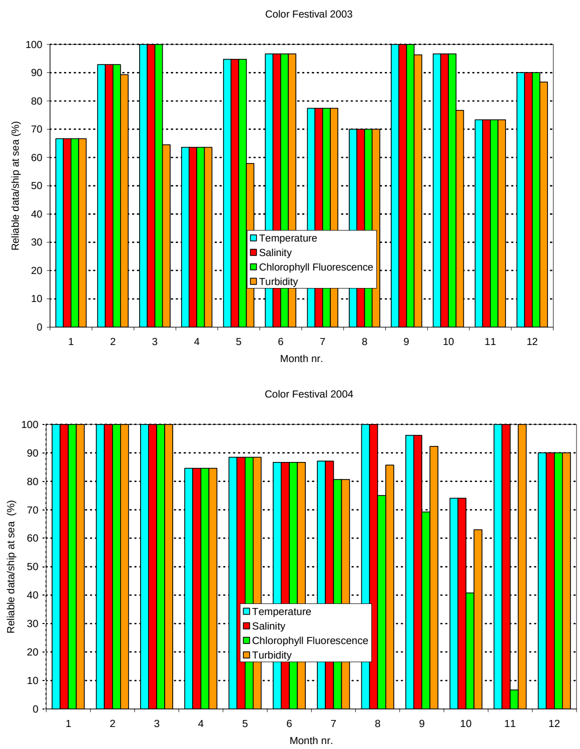

Figure2. Plot of reliable data for the Skagerrak ferry route in 2003 (top) and 2004 (bottom).

Examples for the data obtained with the Ferrybox systems are displayed in Figures 3-6, that show dot-plots of the 4 core variables for the years 2003 and 2004 again for the Skagerrak line. The data in these plots are quality controlled by removing suspicious data (spikes). Factory or on site calibration of the sensor has been used as well. The turbidity control based on water samples has not been used to correct the data, nor have the chlorophyll-a analyses or irradiance measurements been used to correct for the seasonal or diurnal variations. For the Chl-a fluorescence both night and day fluorescence are used.

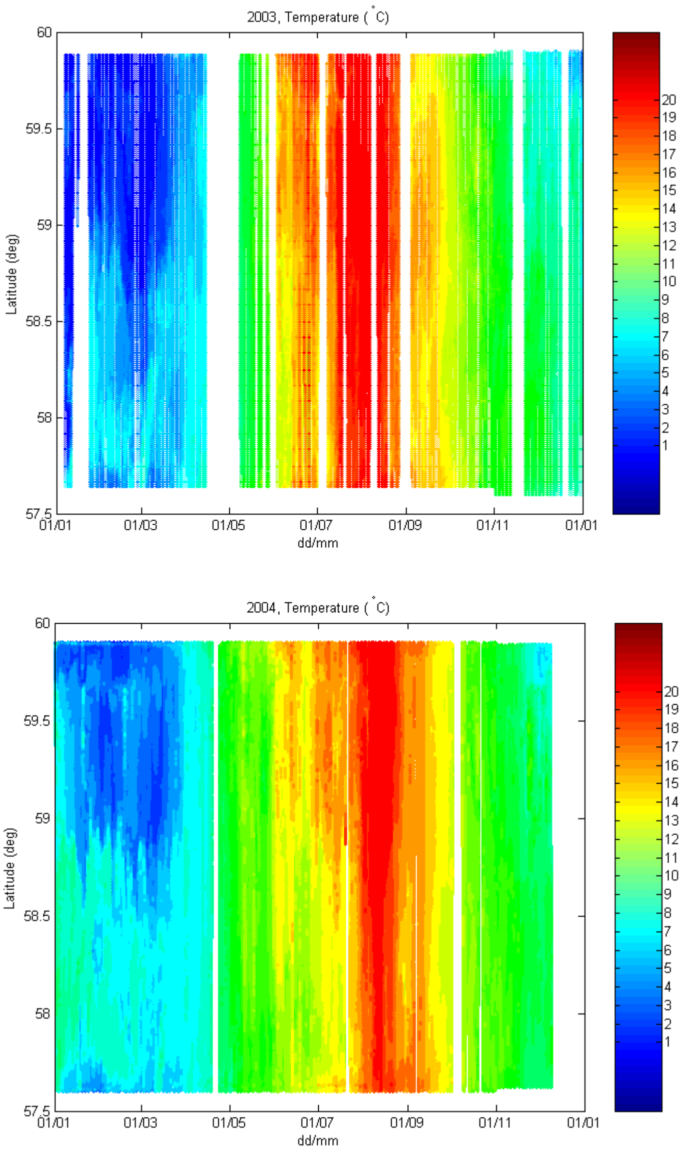

Figure 3. Plot of temperature (°C) for the Skagerrak ferry route from 2003 to 2004.

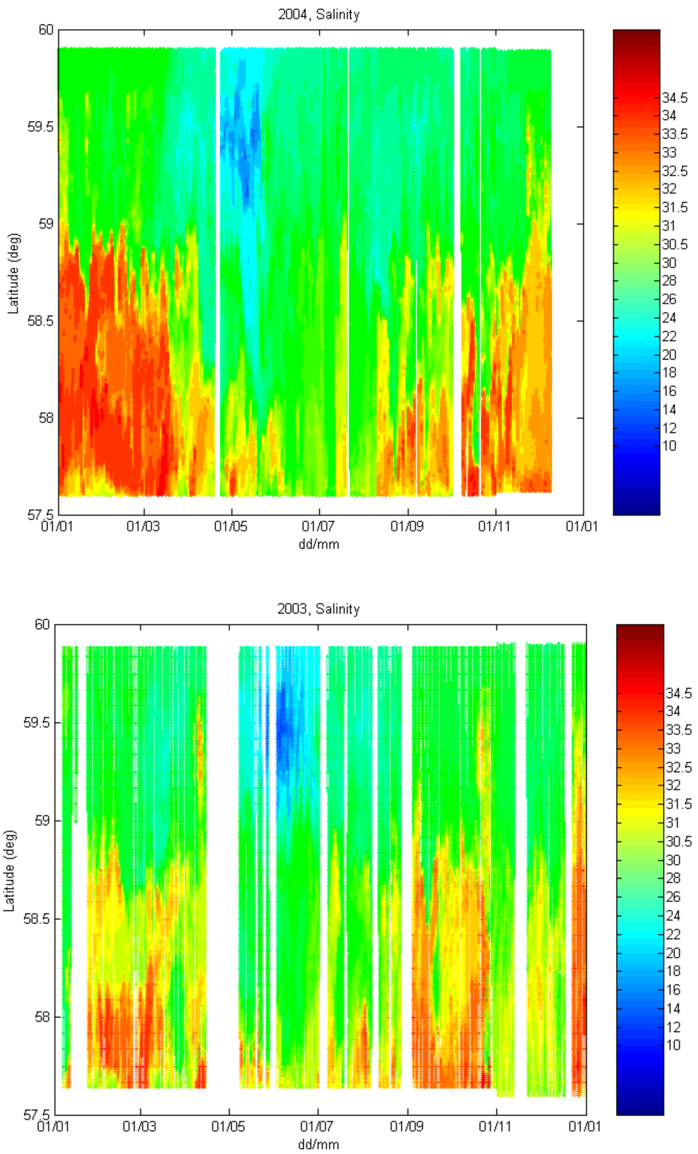

Figure 4: Plot of salinity for the Skagerrak ferry route from 2003 to 2004

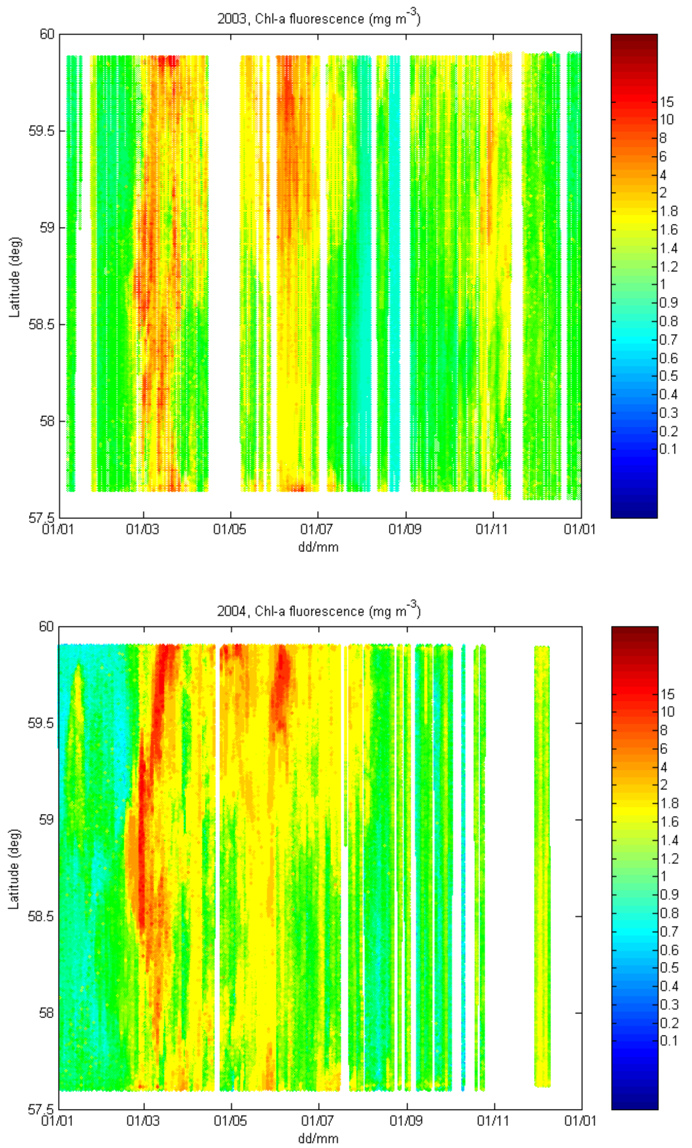

Figure 5: Plot of chlorophyll-a fluorescence (µg/l) for the Skagerrak ferry route from 2003 to 2004

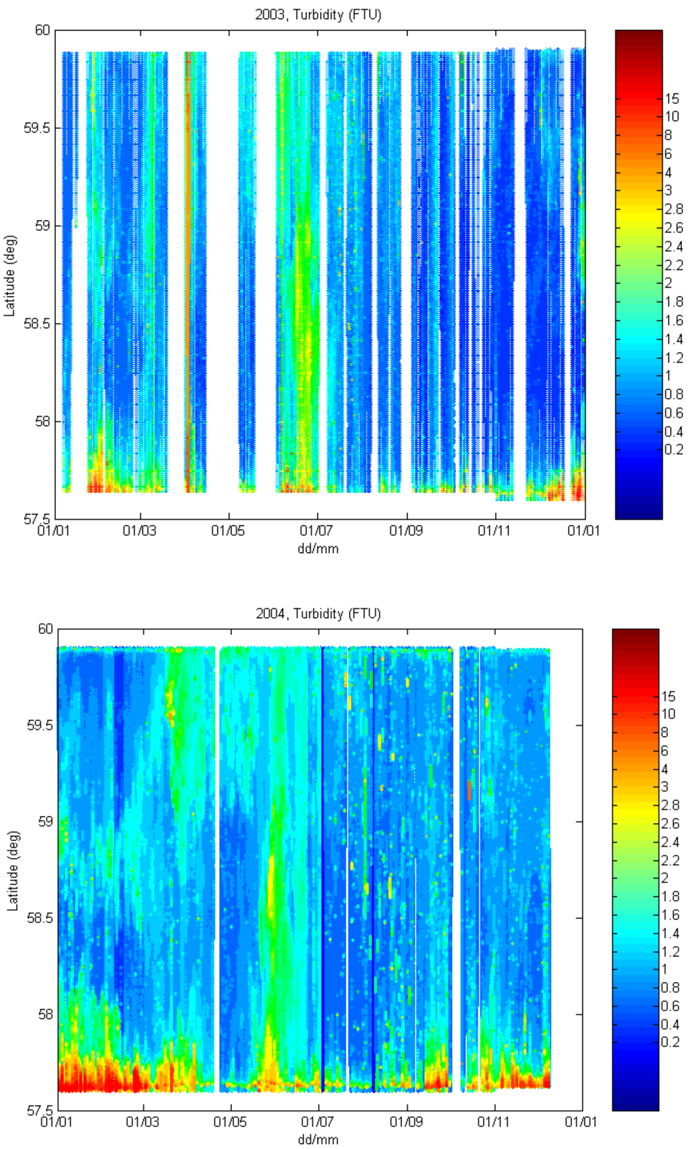

Figure 6: Plot of turbidity (FTU) for the Skagerrak ferry route from 2003 to 2004

Synergy between sampling strategies and the use of numerical models

While the Ferrybox approach can provide good temporal resolution along a defined route spatial extrapolation of such observations needs to be carried out with caution. One approach to enhance the information derived from Ferrybox measurements is to combine with information derived from other platforms. The Ferrybox data were combined with Remote sensing data and numerical models were used to compare Ferrybox data with other observational data in order to increase the significance of the obtained data. Examples of studies carried out are given below.

As an example SmartBuoy measurements in the North Sea carried out by CEFAS are subject of a pilot study to provide measurements that can be combined with similar data from other sources such as spatial data from FerryBox to give greater confidence in environmental assessments. A comparison between SmartBuoy and FerryBox observations was carried together with an application of a hydrodynamic model. Without the application of the hydrodynamic model the comparison between the observations show a poor relationship. However, when water masses measured with the FerryBox were introduced as Lagrangian Tracers in to a General Circulation Model (GCM) their spatial displacement was predicted. The spatial shift in the simulated parameters resulted in a much improved agreement between buoy and FerryBox data. This counts for quasi conservative parameters like salinity. For non conservative parameters like chlorophyll the results remain still unsatisfactory (Figure 7). Therefore a biological module was implemented to estimate the changes in phytoplankton chlorophyll concentration within the time span the water mass is transported from the SmartBuoy to the ferry route. This results in much improved agreement between the two data sets (Figure 8). This study illustrates one method for simulation and quantification of the transport of contaminants contained within water masses.

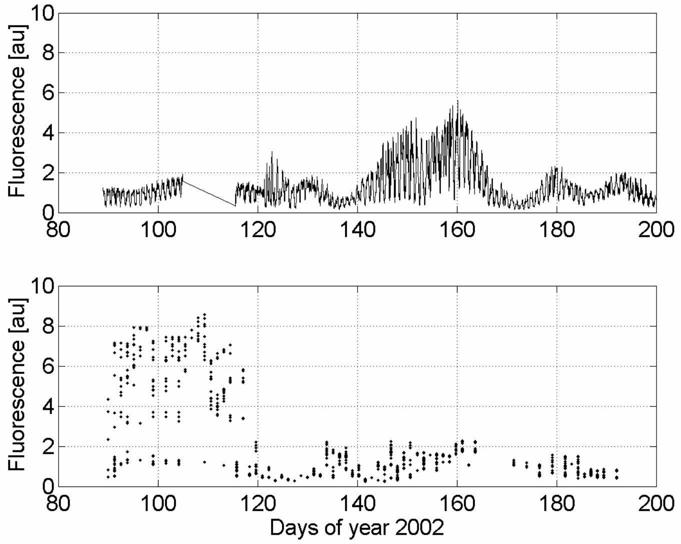

Fig 7 Chlorophyll fluorescence observed at Cefas Gabbard buoy (upper panel) and chlorophyll fluorescence of water passively transported within the GCM (lower panel)

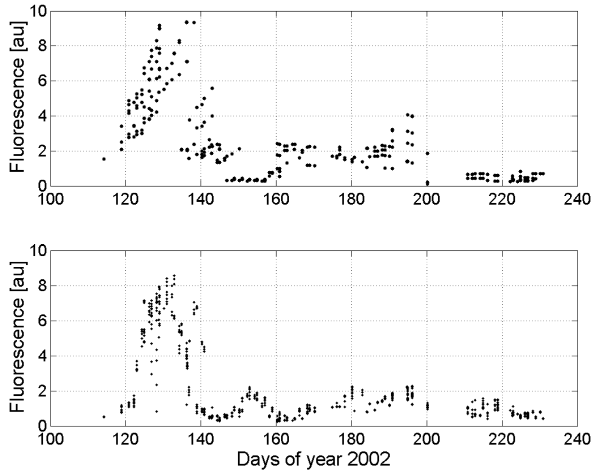

Fig 8. Comparison between observed FerryBox Chl Fluorescence (lower panel) and estimated chlorophyll for tracers starting from the Gabbard and drifting to the FerryBox route (upper panel)

For example, the spatial restriction of a FerryBox to the transect can be overcome for certain parameters such as chlorophyll and suspended matter by combining with results from remote sensing. Figure 9 shows, as an example, the spatial distribution of chlorophyll-a concentration derived from ENVISAT-MERIS (algal-2 for case-2 water) for the Sakgerrak region in March 2003. From the image the spatial extent of the algal bloom already started in the southern part of the route can be clearly seen.

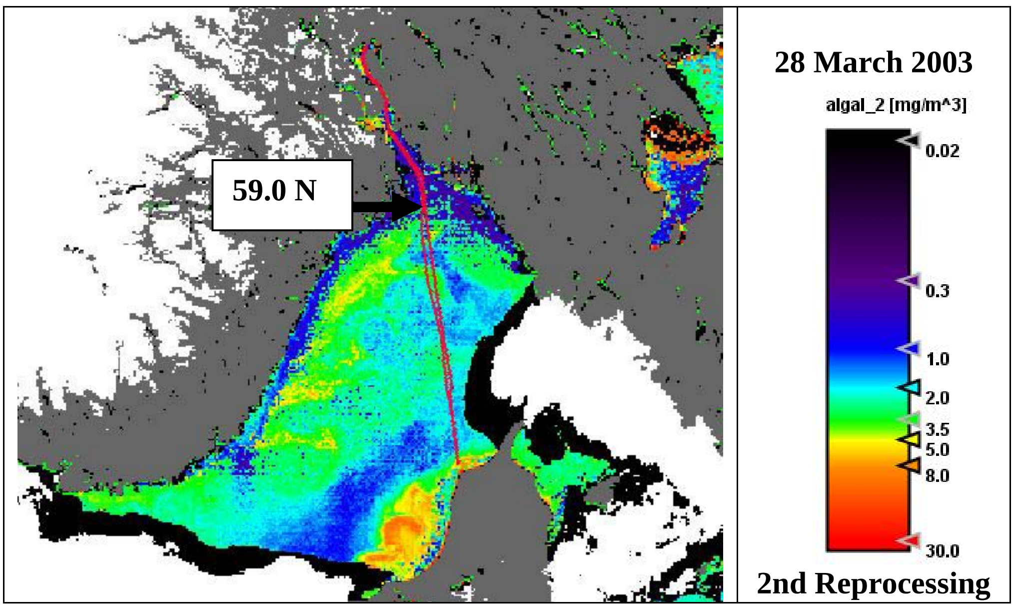

Figure 9: MERIS Algal_2 from the Skagerrak on 28th March 2003 based on the 2nd reprocessing of MERIS.

Figure 10 shows data from 4 situations in 2004 during the first spring bloom in February and March and one from a summer situation in June. The fluorescence is shown together with the water sampled Chl-a and the non-standard MERIS product FLH. From this it is clearly seen that the night fluorescences are in better agreement with the Chl-a and that the difference between night and day can reach a factor 2-3. The overall correlation of the Chl-a and Chl-a fluorescence are good which make it possible to use also the Chl-a fluorescence data for validation, but one need to discriminate between night and day data to have the best comparison.

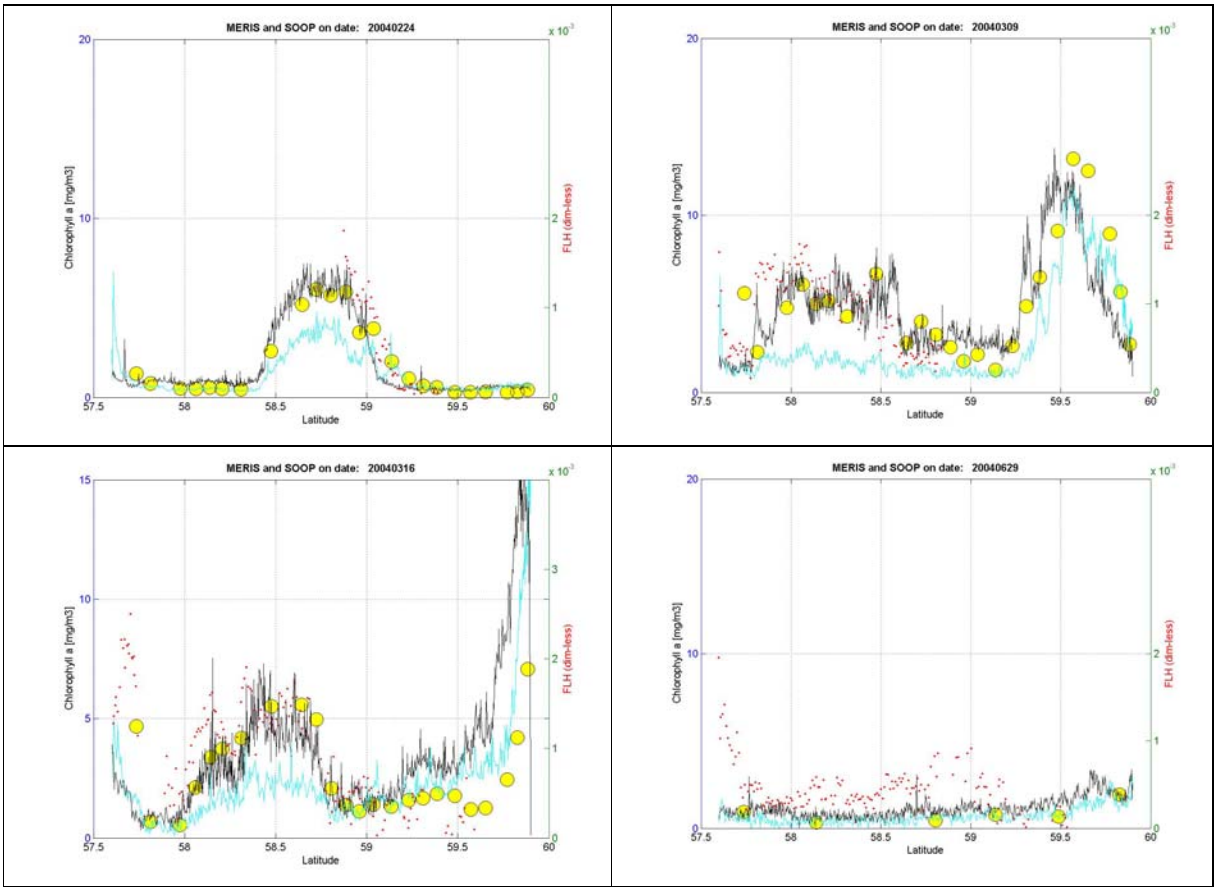

Figure 10: Comparison of the night (black) and day (blue) fluorescence, Chl-a (yellow) and the non-standard product FLH data (red) for some dates in 2004.(Upper left 24 February, upper right 9 March, lower left 16 March, lower right 29 June).

These examples are demonstrating the possibility to improve the overall knowledge of the environmental stage through combining the different observational methods, with individual spatial and temporal characteristics

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