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Validation of methods for monitoring of coastal and open sea areas with satellites and sensors on ships of opportunity

The Research Council of Norway

Color Line

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REPORT

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Abstract

Final report to the Norwegian Research Council. The main objective of the project was to construct, install and test an automatic system for observations of temperature, salinity, chlorophyll fluorescence and turbidity from the cooling inlet aboard the ferry Color Festival (Oslo –Hirtshals). An automatic water sampler makes it possible to analyse other properties of the surface water, such as nutrients and organochlorides at selected positions. The potential of combined satellite and ship-sensor observations is illustrated as well as the use of the system for early warning of harmful algea. Examples are also given of the system's potential for low cost high frequency regular monitoring of the surface layer.

4 keywords, Norwegian	4 keywords, English
1. Observasjoner på fartøy i fast rute	1. Ships of opportunity
2. Overvåking	2. Monitoring
3. Overflatelaget	3. Surface layer
4. Skagerrak	4. Skagerrak

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Validation of methods for monitoring of coastal and open sea areas with satellites and sensors on ships of opportunity.

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Preface

This is the final report for project nr. 143541/431 "Validation of methods for monitoring coastal and open sea areas with satellites and sensor on ships of opportunity" financed by the Norwegian Research Council, the Color Line and the Norwegian Institute for Water Research. The project has been running for 2 years (2001-2002).

The success of the project was heavily dependent on the Color Line (facilities and support). We especially appreciated the friendly and thoroughly assistance from the Chief engineers Odd Johannessen and Eilif Tveitdal and the crew in the engine department. Special thanks to Superintendent Hans A. Nielsen, Color Line.

Oslo, 1.7.2003

Jan Magnusson

Contents

1. Introduction

Use of commercial ships as platforms for observations (ships of opportunity, SOOP) is an old technique in oceanography. From the ship logs the major ocean currents were mapped. In modern times it is mainly used as a low cost system for environmental monitoring and for complementing the meteorologically important surface temperature of the sea.

The need to monitor the environmental status of the oceans actualised this technique. Today several systems are operating in Europe. The oldest is the Finnish system in the Baltic, where not only temperature and salinity are measured, but where also water samples are automatically collected to study several chemical parameters as well as phytoplankton variations (Leppänen et al.1991). The Baltic system is used in combination with satellites as an early warning system for harmful algae as well as a method to study the eutrophication. Today, there are systems running in Japan, Korea, U.S.A (3 ships), Germany (2 ships), England (2-3 ships), Finland (3 ships) and the Netherlands (1 ship).

The use of SOOP in Norway has mainly been temperature measurements along the west coast (Hurtigruten), operated by the Institute of Marine Research (IMR) in Bergen. In order to develop a low cost system for environmental monitoring in Norway the present pilot project was started in 2001.

Other projects are using observations from this project. The data will be used in connection with the ESA and Norwegian Space Center project VAMP - "Validation of MERIS Data Products", the EU-project REVAMP - "Regional Validation of MERIS Chlorophyll Products in North Sea Coastal Waters" and the EU-project DISMAR – "Data Integration System for Marine Pollution and Water Quality".

A new EU-project- “FerryBox” – started in 2002, and we were invited to participate, mainly thanks to the NFR project, as it was one of the few operating systems at the time the proposal was written (October 2001). The FerryBox-project will include testing of different sensors, quality controls, data base development and mechanisms for exchanging observations. Further analyses will be mainly on using the systems for eutrophication studies and exploring the combined use of satellites and the surface observations (validations).

2. Objectives

The primary objective was to construct a system on board a ferry with sensors for continuous measurement of temperature, salinity, chlorophyll fluorescence, turbidity and light. The system should be equipped with an automatic water sampler, thus increasing the range of parameters that could be sampled (mainly nutrients, chlorophyll-a), and phytoplankton.

And:

- Testing the quality of the sensors compared to standard measurements.
- Illustrate the potential of combined satellite and ship-sensor observations
- Explore the system's possibility as an early warning system for harmful algae.

All these objects have been worked with, but the priority has been on the first part, - constructing and running the system.

3. Description of the system

3.1 Selection of platform

Selection of a platform for the constructing and testing of a system was primary made with the purpose of easy accessibility, which means a ferry with Oslo as a harbour. Since the Skagerrak and the Oslofjord constitute an area of general environmental interest, we selected the ferry between Oslo and Hirsthals (Denmark). This route – run by the Color Line- was mostly daily, with one night passage (18 – 06 UTC) and one return in the day (8-16, UTC). The distance between Oslo and Hirtshals is about 140 n.m (Fig.1)

The Color Line supported the project with most of the needed installation on board and free rides with the ship (Color Festival) whenever needed (calibration and control of the system). This help proved to be crucial for the success of the project.

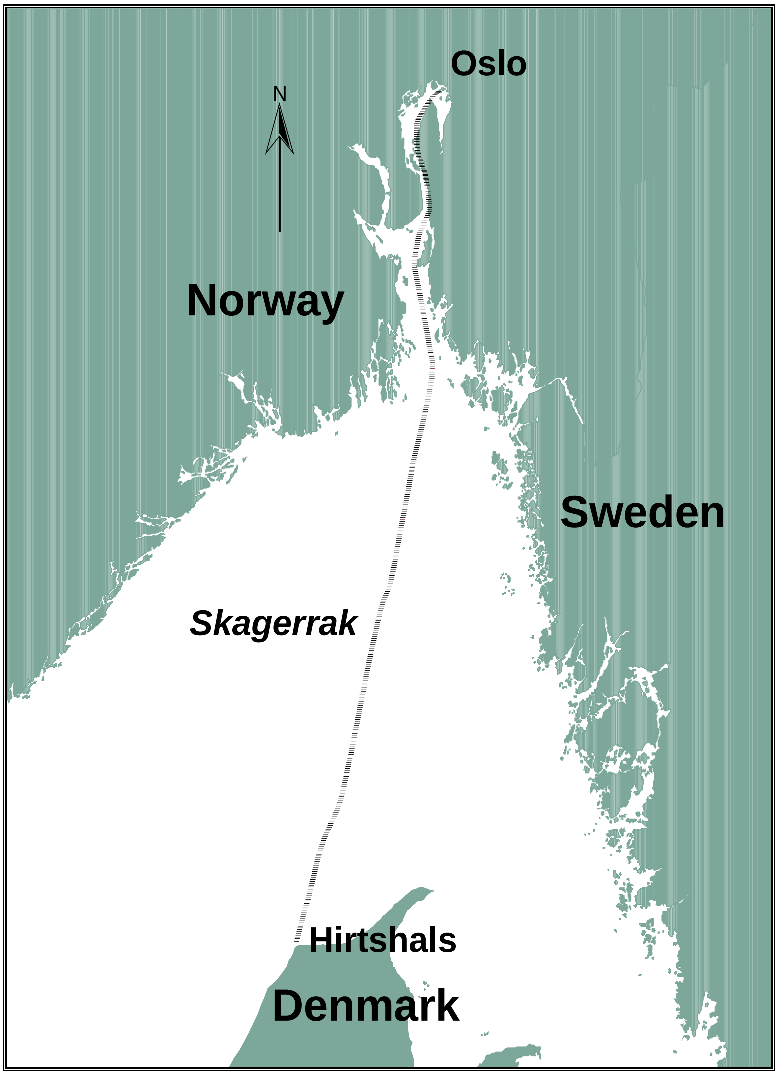

Figure 1. The Color Festival route between Oslo and Hirsthals.

3.2 Installation and instruments

The system should be low cost, but with a sufficient quality for surface water observations. Thus the following sensors and equipment were chosen:

Temperature and salinity

Temperature and salinity (conductivity) are measured with a SEABIRD SBE 45 Micro TSG (thermosalinograph) (fig.2). The TSG is constructed of plastic and titanium, thus ensuring long life with minimum maintenance. The sensors are well proven and well known. The temperature drift is about 0.002 °C pr. year. Initial accuracy is 0.002°C. The conductivity sensor is not sensitive for fouling. Initial accuracy is 0.003.

Communication with the MicroTSG is over an internal, 3-wire, RS-232C link, providing real-time data transmission.

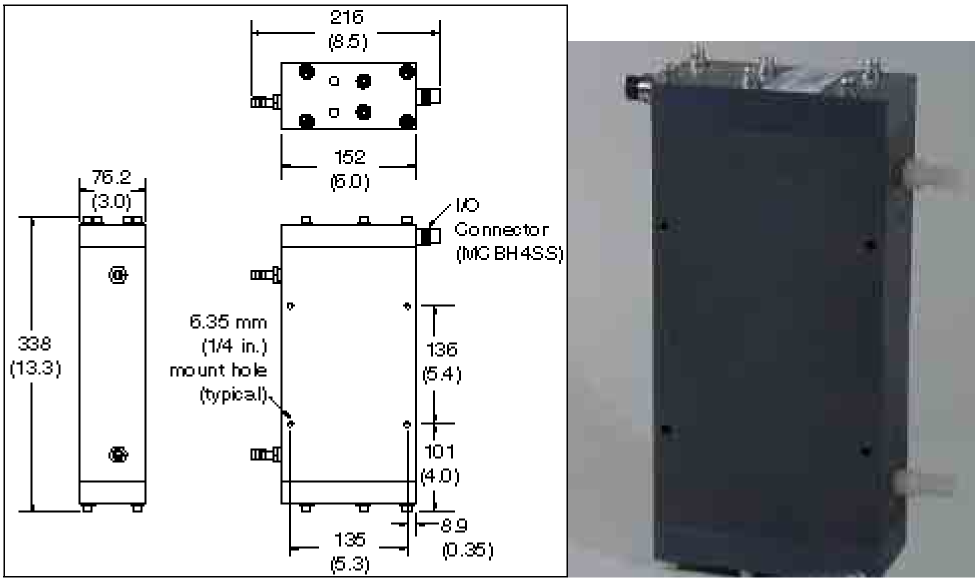

Figure 2. The SEABIRD SBE 45 Micro TSG.

Chlorophyll fluorescence

The chlorophyll sensor is a Seapoint fluorescence sensor (fig.3)). The excitation wavelength is 470 nm and the emission wavelength 685 nm. The sensing volume is 340 mm3. Minimum detection level is 0.02 µg/l.

Turbidity

The turbidity sensor is from Seapoint with electrical output 0-5.0 VDC. Light source wavelength is 880 nm (**Figure 4**).

The manufacturer specifies that the optical design confines the sensing volume to within 5 cm of the sensor, allowing near-bottom measurements and minimising errant reflections in restricted spaces. This, however, is not correct since wall interference can exist up to 9 cm.

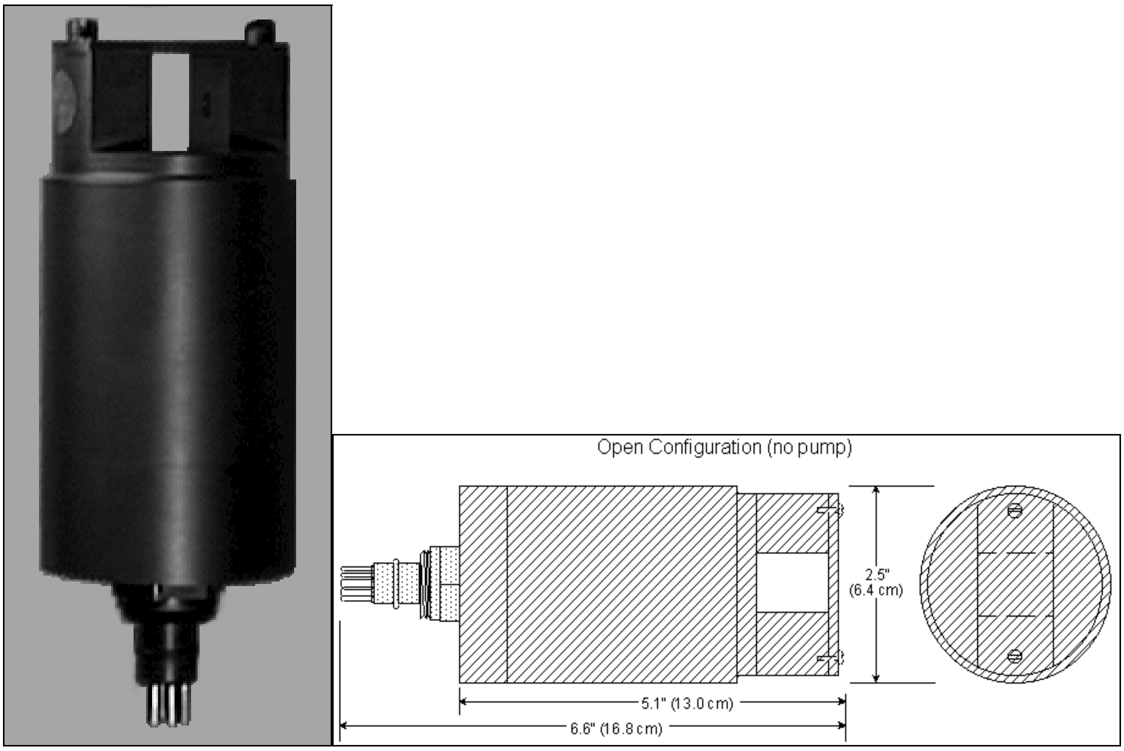

Figure 3. The Seapoint fluorometer, range 0-15 µg/l.

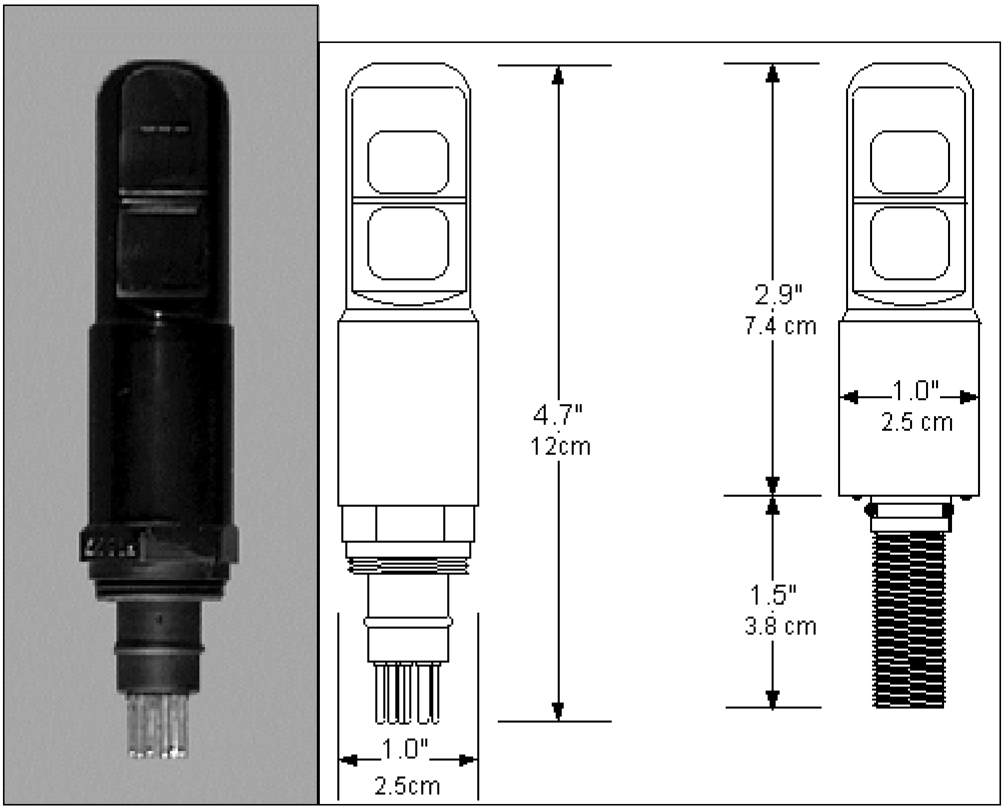

Figure 4. Seapoint turbidity sensor (0-25 FTU).

Photosynthetic available light (PAR)

The light sensor is a Li-Cor Li-190SZ Quantum sensor (cosine sensor), placed on the bridge wing. Signals are logged on the computer in the engine room.

Refrigerated water sampler

Sampling of water at pre-selected positions is made by a refrigerated automatic water sampler (ISCO, Figure 8), with 24 bottles (the volume for each bottle is 1 liter). The water sampler can be programmed to sample one or several bottles at the selected positions.

Software

The system is controlled by computer software (Lab View 6.0).

The ships geographical position is collected from the ships own DSGPS, and together with the PAR-measurements, located at the bridge wings, the signals are transferred to the computer in the engine room.

Intake of seawater had to be from existing inlets as new inlet demand docking of the ship. Next docking was at the end of April 2003; thus a new inlet was installed.

The inlet was placed at the port side main cooling water inlet in the box from which the engine cooling water passes before entering the cooling system. At the inlet a high-pressure driven valve regulates the water inlet (on/off) through programmed positions. So far this regulation has been used to close the inlet of water before the ship enters the harbours. From the inlet the water is brought to a de-bubbling chamber before entering the TSG. After the TSG the sensor chamber with Chlorophyll sensor and turbidity is situated. From the sensor chamber the water is lead to a small (3 l) box with overflow into a larger box that empties to the ship's discharge system. Water to the refrigerated water sampler is taken from the3 liter box and pumped due to a signal initiated from pre-chosen positions (waypoints). The pump is of a peristaltic type as not to interfere with biological samples (phytoplankton). The main features of the system are shown in Figure 5. Details are in Figure 6 - Figure 8.

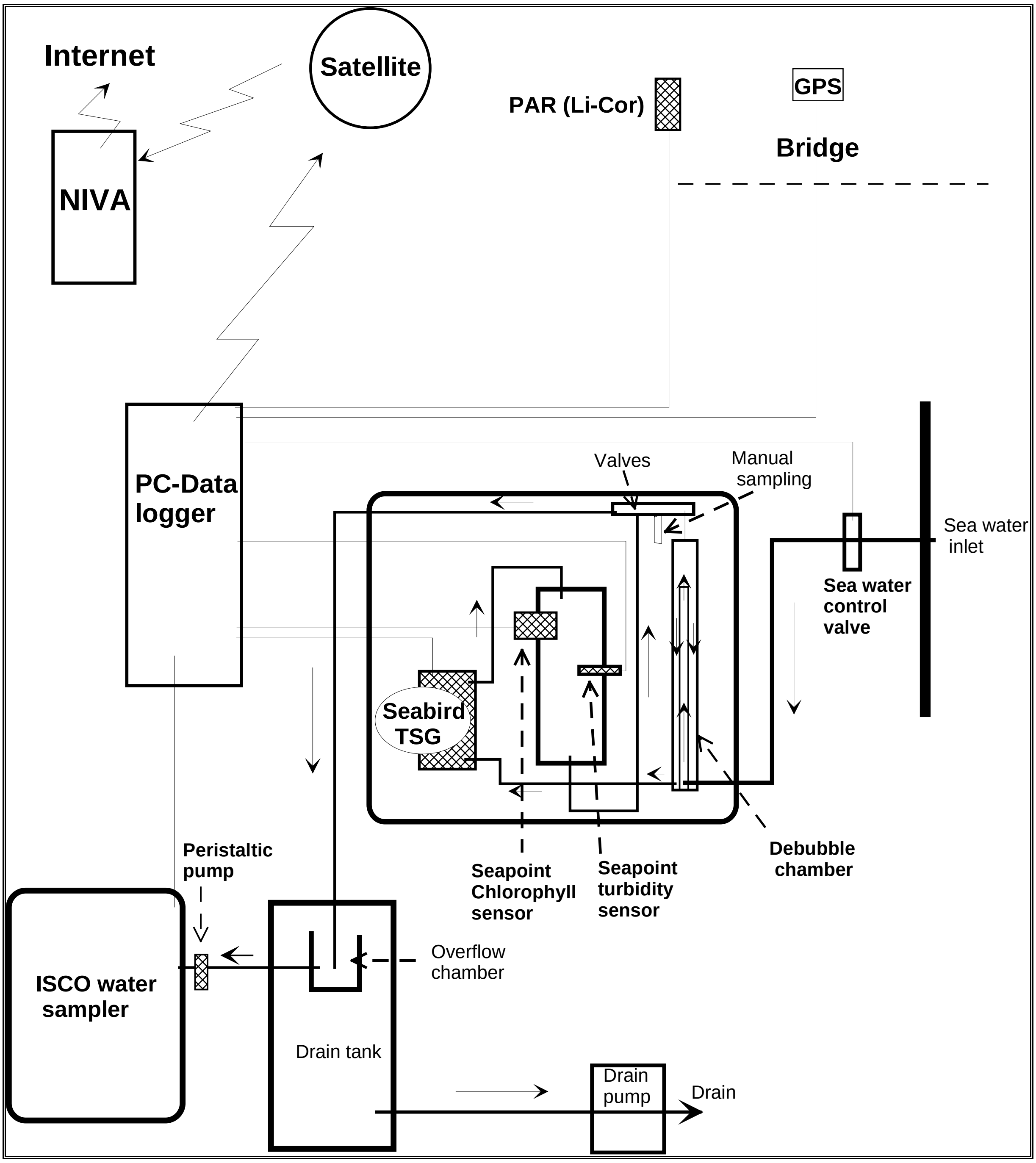

Figure 5. Overall view of the system. Details in **Figure 6 - Figure 8**.

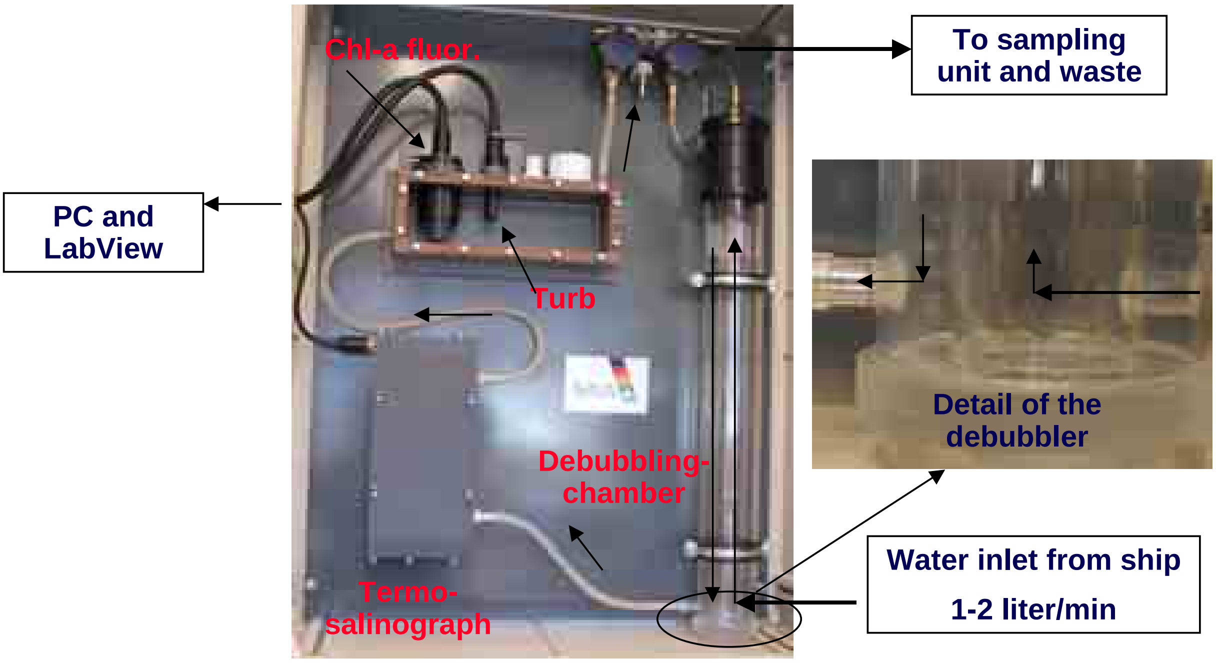

Figure 6. Cabinet with sensors and de-bubble chamber. Version 1. Later the sensor chamber was replaced with a vertical cylinder.

Figure 7. New sensor chamber (version 2) from 11.6.2002- 14.4.2003.

Figure 8. The ISCO water-sampling unit.

3.3 Data handling and presentation

Lab View 6.0. is used for collecting and processing the observations. On board all data are collected in a simple log file. The log file updates each minute, which is the selected sampling interval. This results in about 460 observations during the day cruise (ship speed about 20 – 22 knots) and 790 samples during the night when the ship has reduced speed (about 10 – 11 knots). This also means that an observation is taken each 600 m during daytime and about each 300 m during the night.

Table 1. Example of log file. Pump = 1 means that water is running in the system. Pump = 0 means that the water inlet is closed. Sample = this is the number of the water bottle filled.

Date	Time	Pump	Sample	Turbidity (FTU)	Chlorophyll fluorescence (µg/l)	Light $\mu Em^{-2} s^{-1}$	Temperature (°C)	Salinity	Longitude	Latitude
21.03.2002	09:09:42	0	0	23.95	2.07	920	15.34	25.84	9.961	57.596
21.03.2002	09:10:42	0	0	23.95	2.04	873	8.75	31.57	9.959	57.598
21.03.2002	09:11:42	1	0	23.94	2.18	884	8.86	31.49	9.957	57.601
21.03.2002	09:12:42	1	0	23.94	2.31	846	8.03	31.53	9.956	57.605
21.03.2002	09:13:43	1	0	23.95	2.00	897	7.64	31.53	9.957	57.609
21.03.2002	09:14:43	1	0	23.94	1.72	908	7.25	31.53	9.959	57.613
21.03.2002	09:15:43	1	0	23.94	2.22	893	7.02	31.56	9.961	57.618
21.03.2002	09:16:43	1	0	23.94	2.06	897	6.96	31.57	9.963	57.623
21.03.2002	09:17:43	1	0	23.93	2.24	891	6.79	31.59	9.965	57.628
21.03.2002	09:18:43	1	0	23.94	2.02	895	6.61	31.64	9.968	57.633
21.03.2002	09:19:44	1	0	23.94	1.92	900	6.51	31.67	9.97	57.639
21.03.2002	09:20:44	1	0	23.93	1.67	907	6.36	31.90	9.973	57.644
21.03.2002	09:21:44	1	0	23.34	1.89	899	6.15	32.14	9.975	57.65
21.03.2002	09:22:44	1	0	21.77	1.56	904	6.10	32.24	9.978	57.655
21.03.2002	09:23:44	1	0	21.32	1.46	900	6.35	32.21	9.981	57.661
21.03.2002	09:24:44	1	0	14.81	1.33	913	5.91	32.50	9.984	57.666
21.03.2002	09:25:45	1	0	12.15	1.17	924	5.78	32.60	9.987	57.672
21.03.2002	09:26:45	1	0	9.94	1.56	909	5.78	32.63	9.99	57.677
21.03.2002	09:27:45	1	0	9.02	1.00	913	5.78	32.64	9.993	57.682
21.03.2002	09:28:45	1	0	8.03	0.94	933	5.80	32.65	9.996	57.688
21.03.2002	09:29:45	1	0	7.25	0.90	922	5.82	32.66	9.998	57.693
21.03.2002	09:30:45	1	0	7.60	0.89	943	5.81	32.67	10.001	57.699
21.03.2002	09:31:45	1	0	6.99	0.86	918	5.80	32.68	10.004	57.704
21.03.2002	09:32:46	1	1	7.00	0.89	941	5.78	32.70	10.007	57.71
21.03.2002	09:33:46	1	1	7.02	0.82	921	5.77	32.72	10.01	57.715
21.03.2002	09:34:46	1	1	6.58	0.87	942	5.77	32.75	10.013	57.721
21.03.2002	09:35:46	1	1	6.50	0.79	940	5.77	32.77	10.017	57.727
21.03.2002	09:36:46	1	1	6.49	0.79	941	5.78	32.79	10.02	57.732
21.03.2002	09:37:46	1	1	5.79	0.82	954	5.80	32.84	10.023	57.738
21.03.2002	09:38:46	1	1	5.24	0.80	938	5.81	32.91	10.026	57.743
21.03.2002	09:39:47	1	1	5.08	0.78	967	5.81	32.97	10.029	57.749

The log file is transferred by Internet to NIVA, updated each minute and stored.

Preliminary results are also distributed on the Internet. The web-site updates every minute (**Figure 9**). The heading gives the system status, date, time and the latest position together with the latest observations. The picture shows the ship position and the graphs the history of the latest cruise.

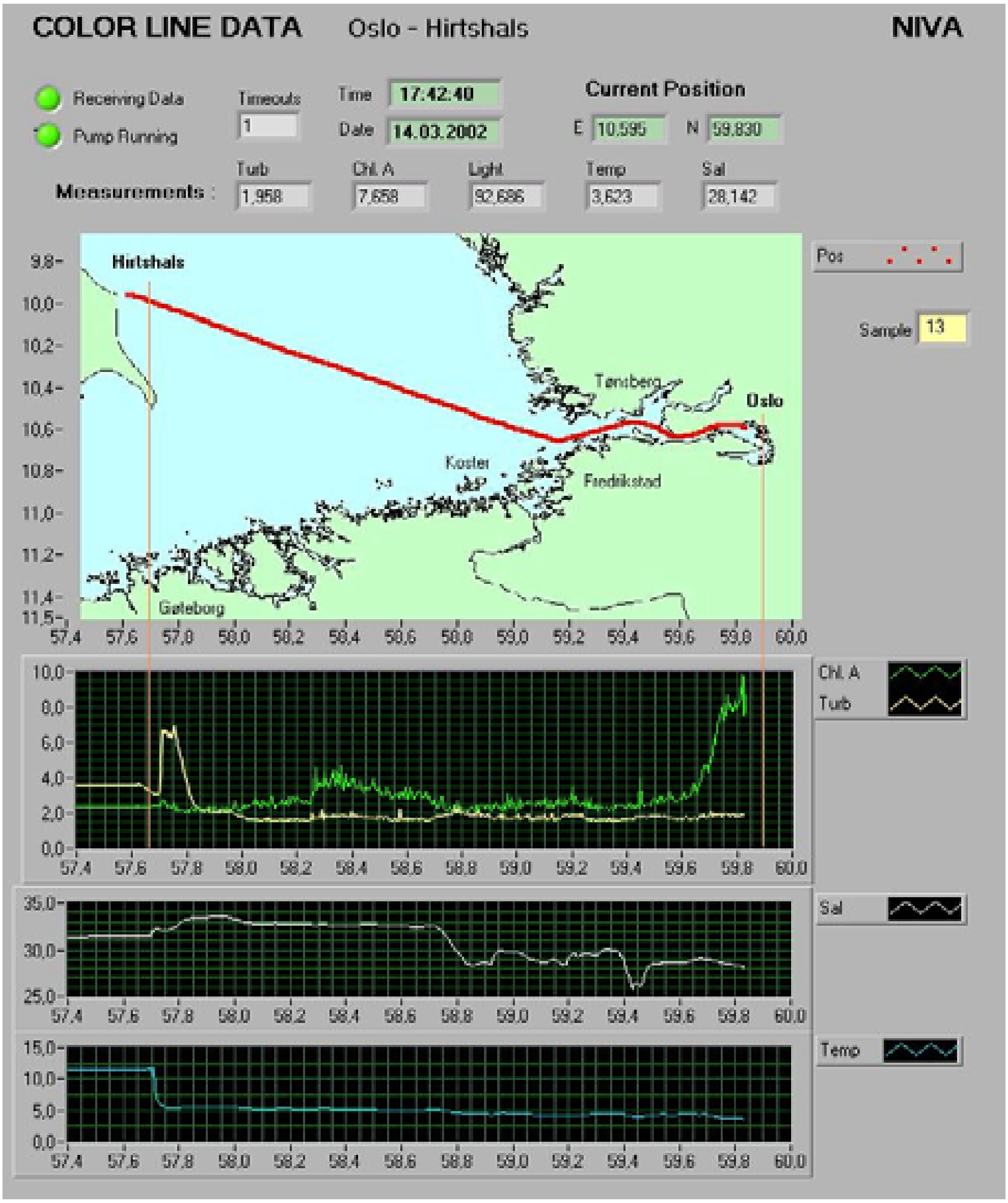

Figure 9. Information displayed on Internet. Color Festival has reached the inner Oslofjord and water sample number 13 has been released. In this case we sampled 2 litres pr. station.

4. History

The system was built and tested in the laboratory from May to July 2001. It was transferred in August to the ferry (Color Festival). The first test was carried out on the 27.8.2001. However, the communication via Internet was first operating in December 2001.

Between December 2001 and March 2002 several minor problems in the communication system were corrected. In April a regular collection of phytoplankton samples started (once a week) in order to test the system as an early warning system for harmful algae. This programme continued during the summer and the early autumn.

During the early spring the problem with accumulation of particles in the sensor chamber became evident. Growth in the inlet valve also reduced the amount of water passing into the system. Routines for cleaning the intake were established. In June a new sensor chamber was installed to avoid particle accumulation in the chamber. The horizontal sensor-box was exchanged with a vertical cylinder. (Figure 7).

Minor adjustments were made during the autumn. The Internet connection worked fine and several scientists in Scandinavia and Europe had access to the observations.
During the project we made some experiences worth mentioning in order to avoid these problems in the future.

We used the ship's DGPS-navigator. This became a problem. Several times there were minor changes on the bridge (updating, changing of instruments etc.). Almost every time when there was work on the navigator, the DGPS signal was lost from the system. It is therefore highly recommended to use a separate DGPS, since the whole system depends on the DGPS.

Using Internet to transfer on-line observations has been an advantage. This will also open up for two-way communication. However, in December 2002 the system was hacked, and our PC was used as a server of an unknown user continuously sending large amounts of data. This did not interfere with our observations, but forced us to install a firewall.

Intake of water should be specially constructed. It is essential to have easy access to clean the inlet from marine fouling. Furthermore, the distance between sensors and inlet should be as short as possible.

A new inlet is planned, as the ferry will dock in April 2003.

The water flow through the system is driven by pressure. This is an advantage as far as reliability is considered. Only two pumps are necessary, one for the discharge of water and one for pumping water to the water sampler. The pumps must have overheating protection. We learned the lesson from one small fire.

Lab View is excellent software to use since it contains all the possibilities needed. However, the programme version contained one bug in the Internet module. The problem was that the Internet connection is interrupted when the ferry turns around in the harbour (the antennas must be rotated). This should not be a problem, as the programme should catch up automatically when signals are received again. This was not the case in Lab View 6.0. Loading an older version of this module solved the problem.

In April 2003 the ship was singed for repairs. This was the first opportunity to open up a new inlet close to the instruments (1m). Several changes were made due to the experiences with the “old” system.

5. Sensor testing

5.1 Turbidity

The sensor was tested in the laboratory in the sensor chamber before transferring to the ferry (Figure 10). The turbidity sensor was then tested against standard solutions on board the ship or against water samples collected by the system.

Turbidity is a relative measurement. The sensor measures in a small volume of water, within 5 cm from the cell according to the instrument manufacturer. Tests showed that this was not true. The cell gives wall-effects up to about 9 cm.

The correlations between the sensor and the different controls were not satisfactory (Figure 11-Figure 14). However, the last test carried out in May 2003 showed that this could hardly be caused by the sensor.

Most of the tests were made by using the water sampler on board. The water was later analysed at the laboratory with a Hach turbidimeter at 860 nm. Only the first and the last tests were made with prepared solutions in the sensor chamber.

Part of the problem with the other tests is possibly due to low concentrations in a limited range, but the main problem seems to be accumulation and uneven distributions of particles in the sensor chamber. The first version of the sensor chamber was visually as well as from the recordings accumulating particles, especially during spring/summer. The main cause was fouling in the intake valve, and improvement was evident when this was cleaned with high-pressure air blown through the valve. As the construction of the sensor chamber evidently was not perfect, a new chamber was designed and installed 11.6.2002. This was an improvement, but there were still problems.

In April 2003 it was possible to install a new water inlet through the ship's hull. The distance between the sensors and the water inlet was reduced from about 10 meters to 1 meter, and the diameter was increased, thus reducing the flushing time. The whole sensor chamber was re-designed to improve the turbidity measurements.

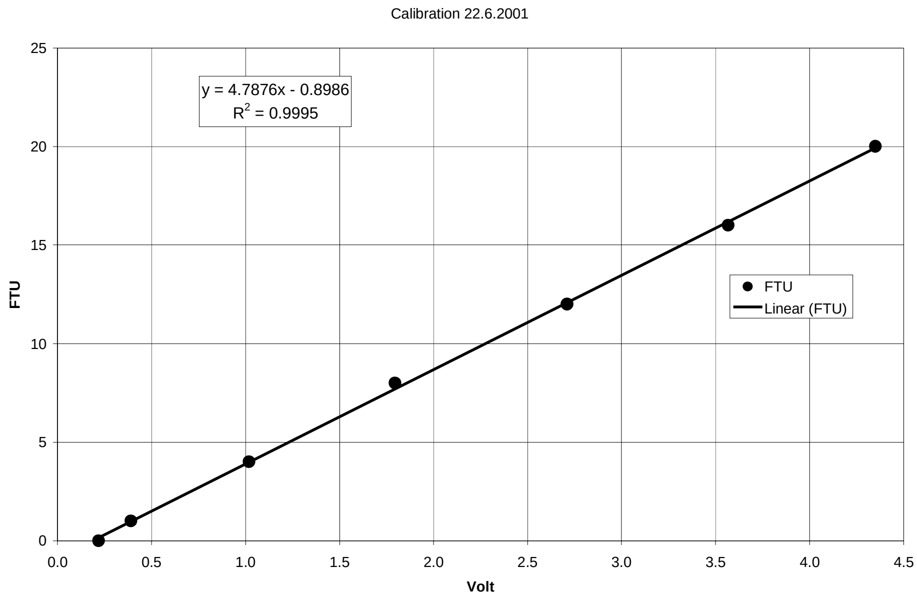

Figure 10. Laboratory calibration of turbidity sensor in sensor chamber with prepared known turbidity solutions.

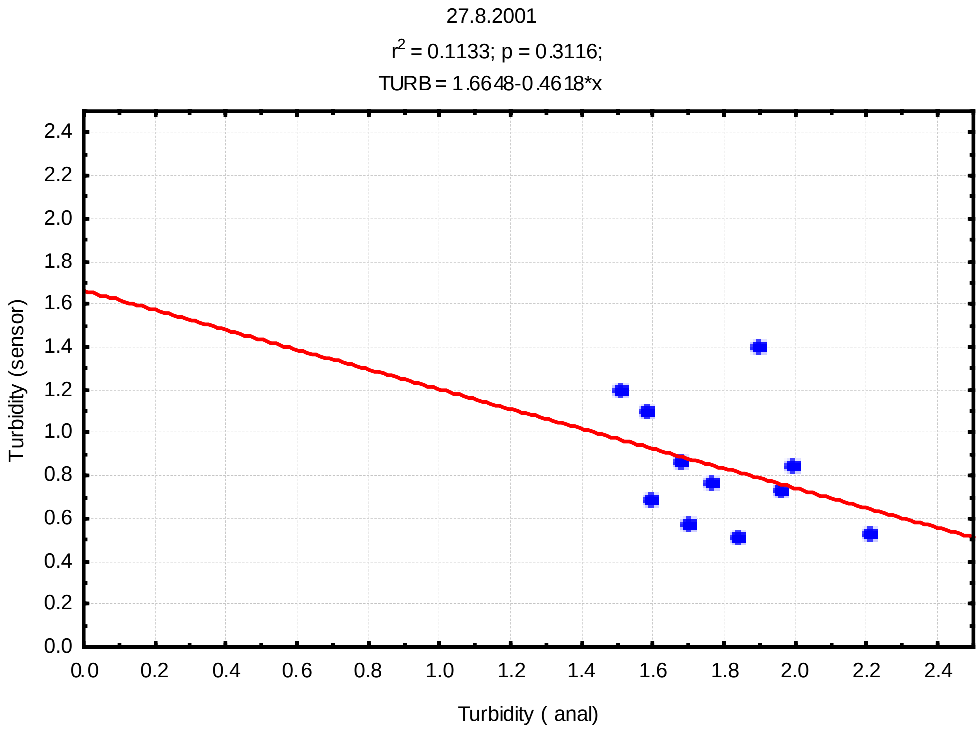

Figure 11. Turbidity control 17.8.2001. Water sample analysed for turbidity in the laboratory.

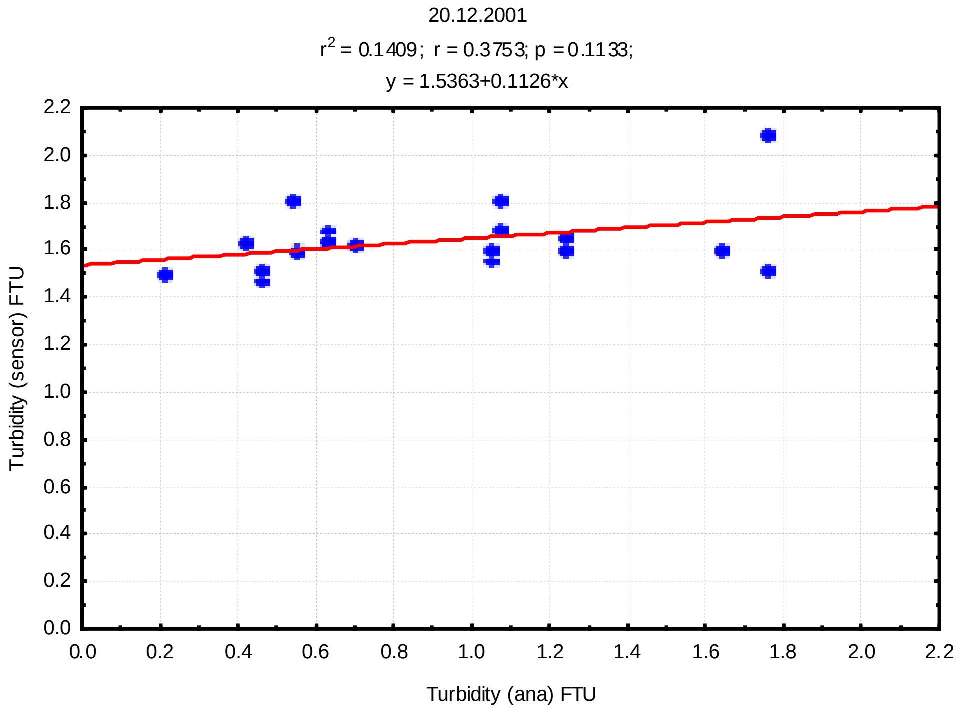

Figure 12. Control turbidity 20.12.2001. Water sample analysed for turbidity in the laboratory

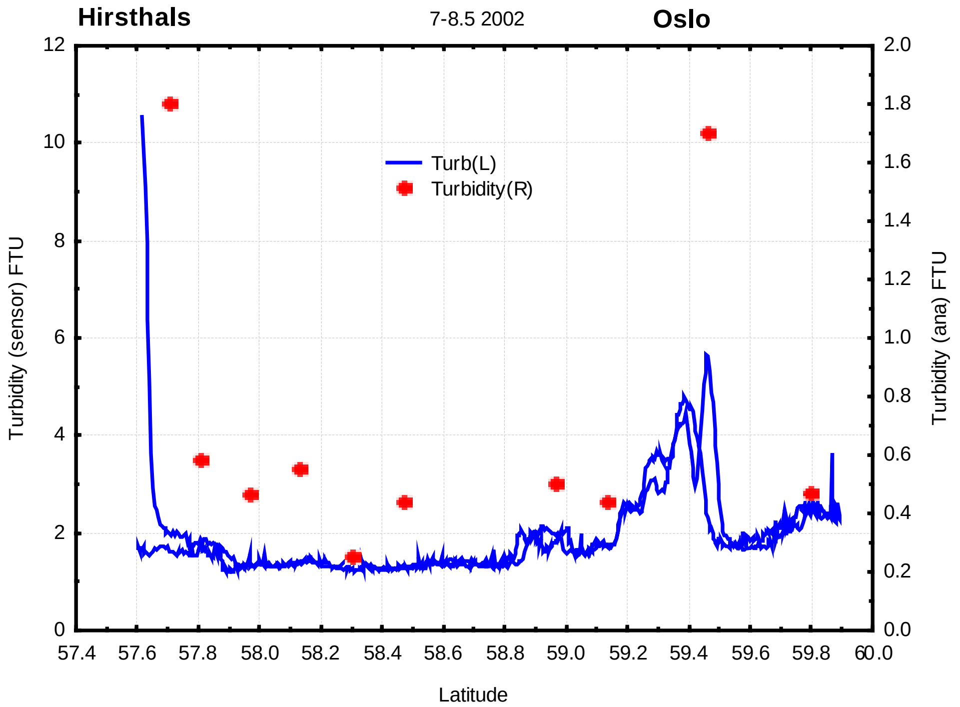

Figure 13. Turbidity control 7-8.5.2002. Oslo - Hirtshals – Oslo. Water sample analysed for turbidity in the laboratory.

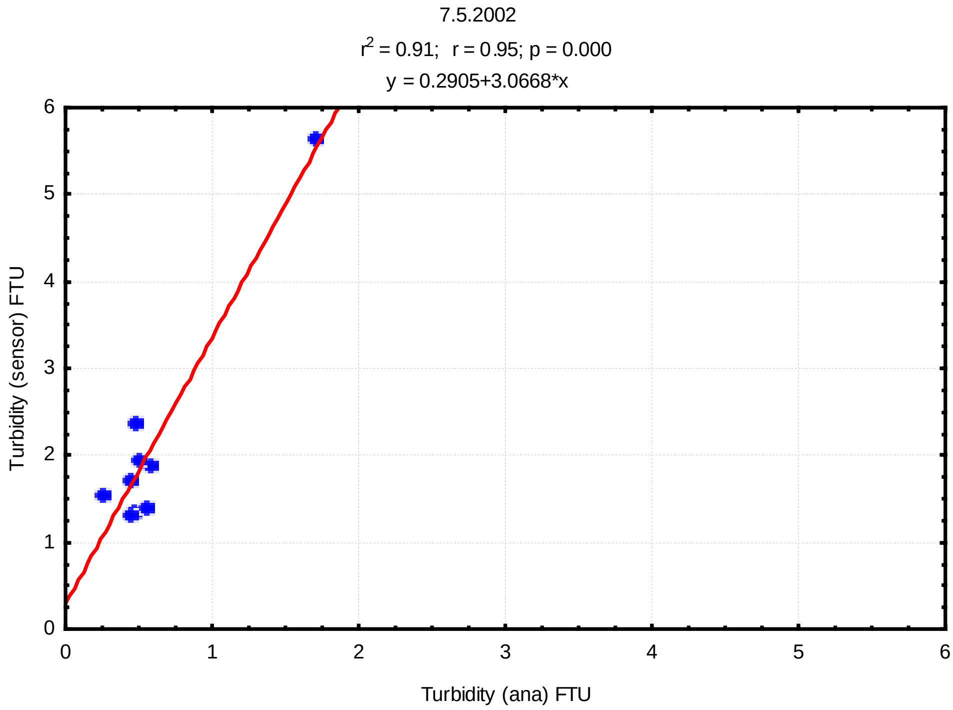

Figure 14. Turbidity control 7.5.2002. Water sample analysed for turbidity in the laboratory.

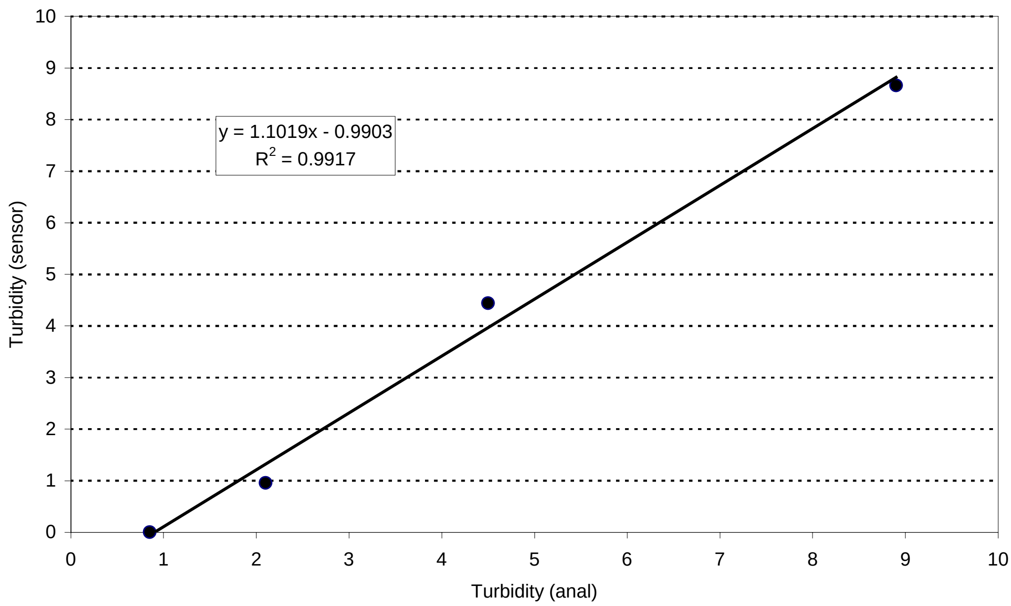

Figure 15. Turbidity control 12.5.2003. Prepared solutions measured in the sensor chamber on board the ship.

5.2 Chlorophyll fluorescence

Chlorophyll-a is used as a measure for phytoplankton biomass in water, but the method is rather crude as the chlorophyll content in phytoplankton generally varies with species and light conditions.

All control tests were made by using water from the water sampler or direct sampling of water at the sensor chamber. The analyses were made at the laboratory using a spectrophotometric method (Richard and Thompson, 1952, modified by Marker et al. 1980). The chlorophyll is extracted with methanol and the extract absorbance is measured at the absorbance maximum (665 nm). Turbidity correction is measured at 750 nm and subtracted.

The sensor measures chlorophyll by using modulated blue LED lamps and a blue excitation filter to excite chlorophyll-a. The fluorescent light emitted by the chlorophyll-a passes through a red emission filter and is detected by a silicon photodiode.

The two methods differ and this represents a problem. The chlorophyll-a fluorescence signal of phytoplankton is connected to the photosynthetic process and is dependent on light conditions (photosynthetic activity) and species. During low light conditions (night) the fluorescence is higher than during day. The overall dependence on light is a higher value 1 – 2 hours after dark, but the light inhibition after a period of dark adaptation is rather rapid –about 15 minutes (Uehlinger, 1985). The laboratory analyses give the chlorophyll-a independent of light conditions, but are of course dependent on the specific species. Thus the use of the chlorophyll sensor is not trivial.

The observations from the 7.5.2002 are of special interest because there are clear differences between night and day observations (Figure 21). The samples for laboratory analyses were made during the day, but it is suggestive that the analysed samples are more similar to the night observations, except around 58.0 °N. However, the correlation between analyses during the day and sensor observations at night was bad. This can partly be explained as due to advection of water masses (Figure 22).

The difference between night and day measurements of chlorophyll was not an objective in this project. The problem will be further explored in the FerryBox project.

The overall correlation between the chlorophyll sensor and analyses is in this context satisfactory. Overall the Chlorophyll sensor explained from 86-96 % of the variation in Chlorophyll–a, except on the 7.5.2002 (Figure 16 - Figure 19). The slope and offset were about the same, except for the last test.

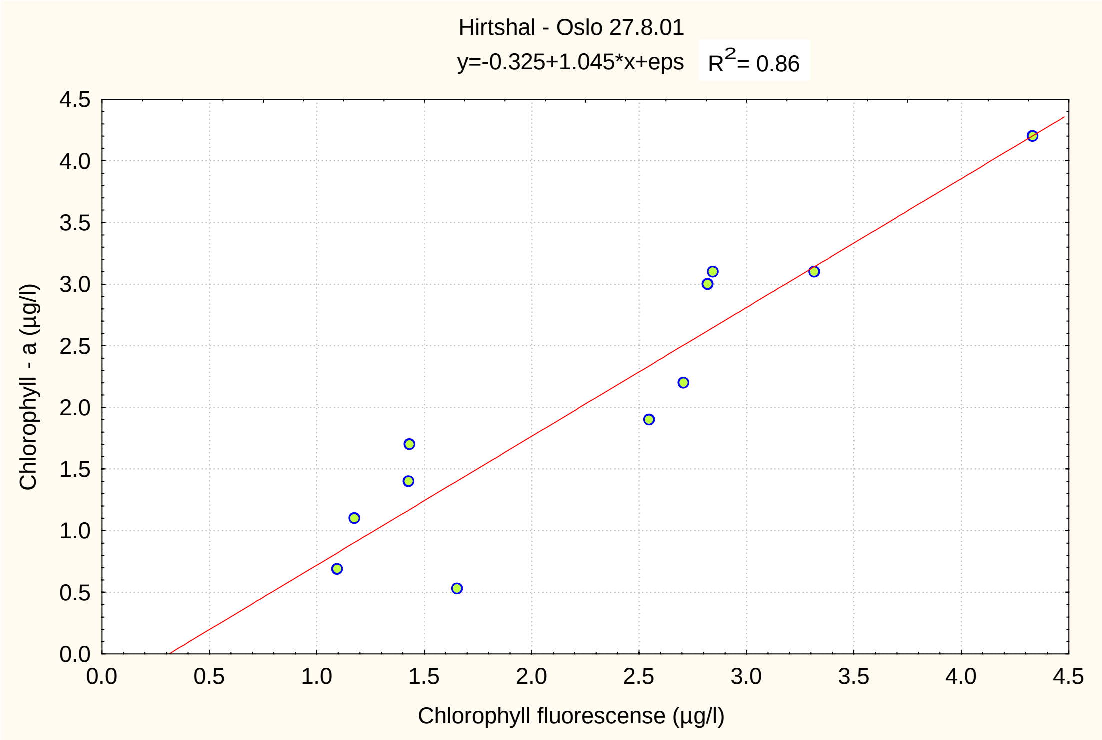

Figure 16. Chlorophyll-a and chlorophyll fluorescence on Color Festival 27.8.2001.

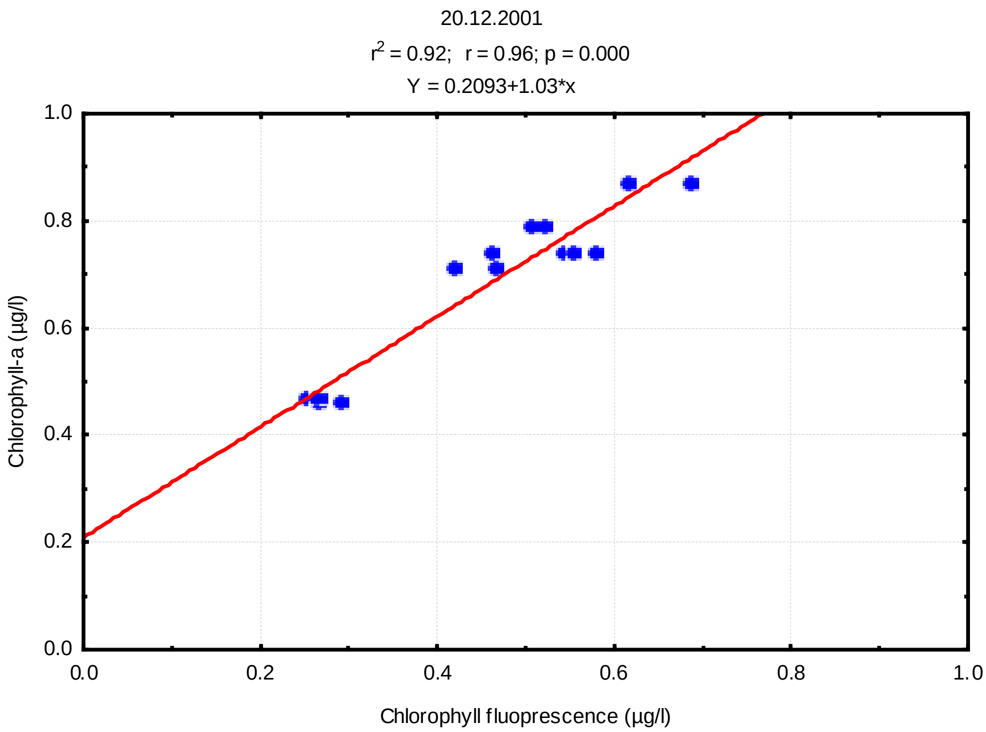

Figure 17. Chlorophyll-a and chlorophyll fluorescence on board Color Festival 20.12.2001

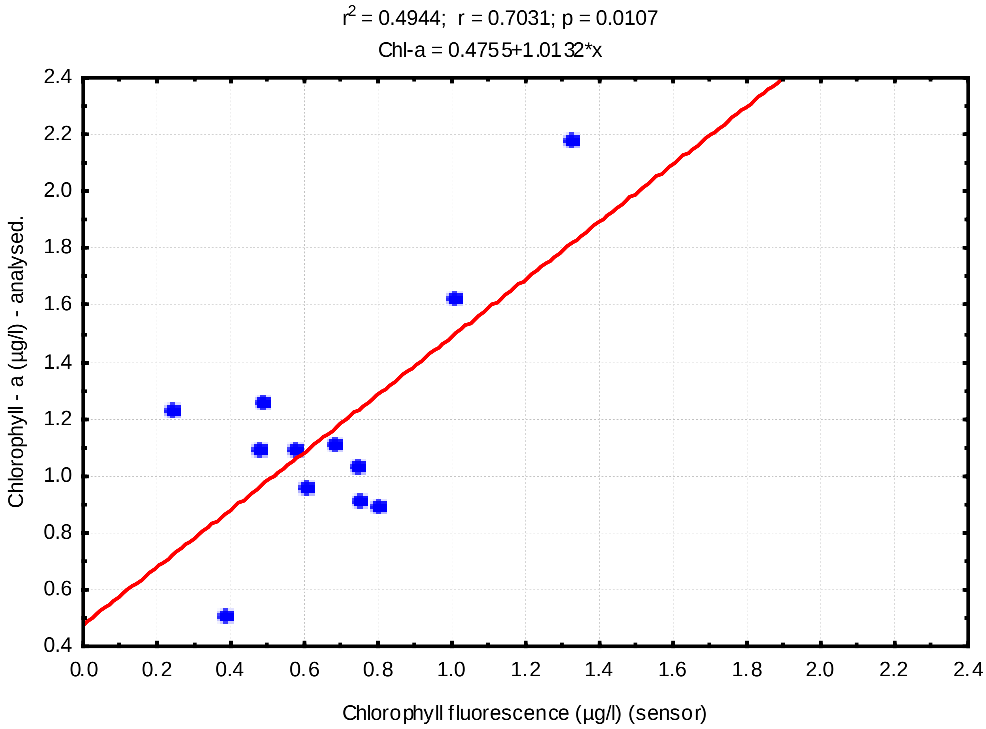

Figure 18. Chlorophyll control 7.5.2002 (daytime).

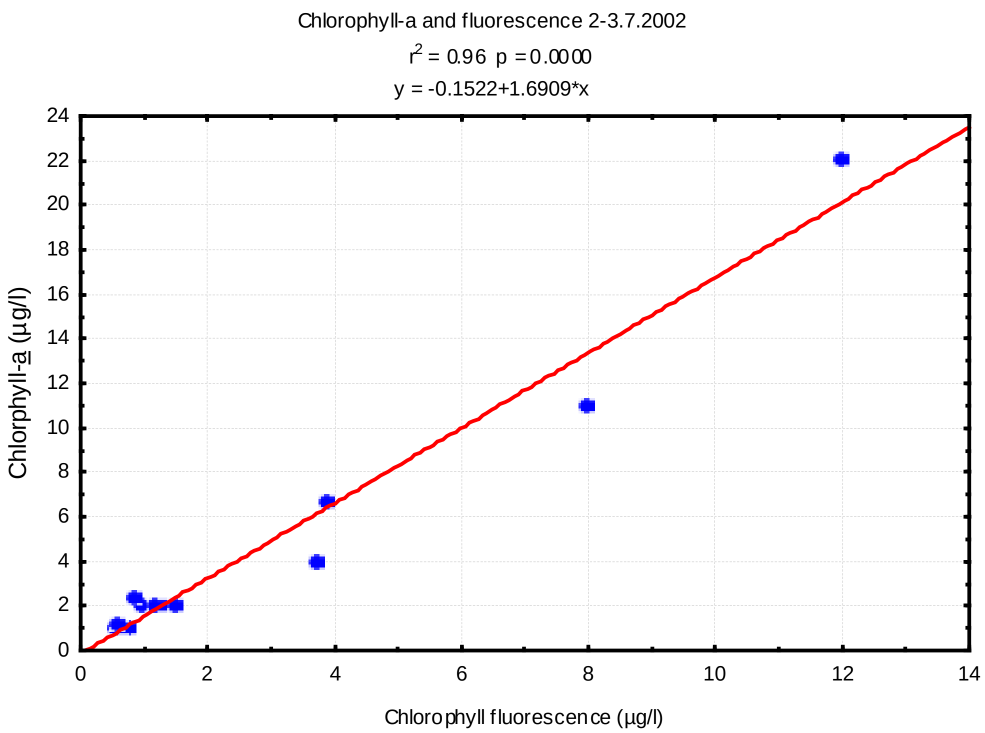

Figure 19. Chlorophyll-a (analysed) and chlorophyll fluorescence 2-3.7.2002.

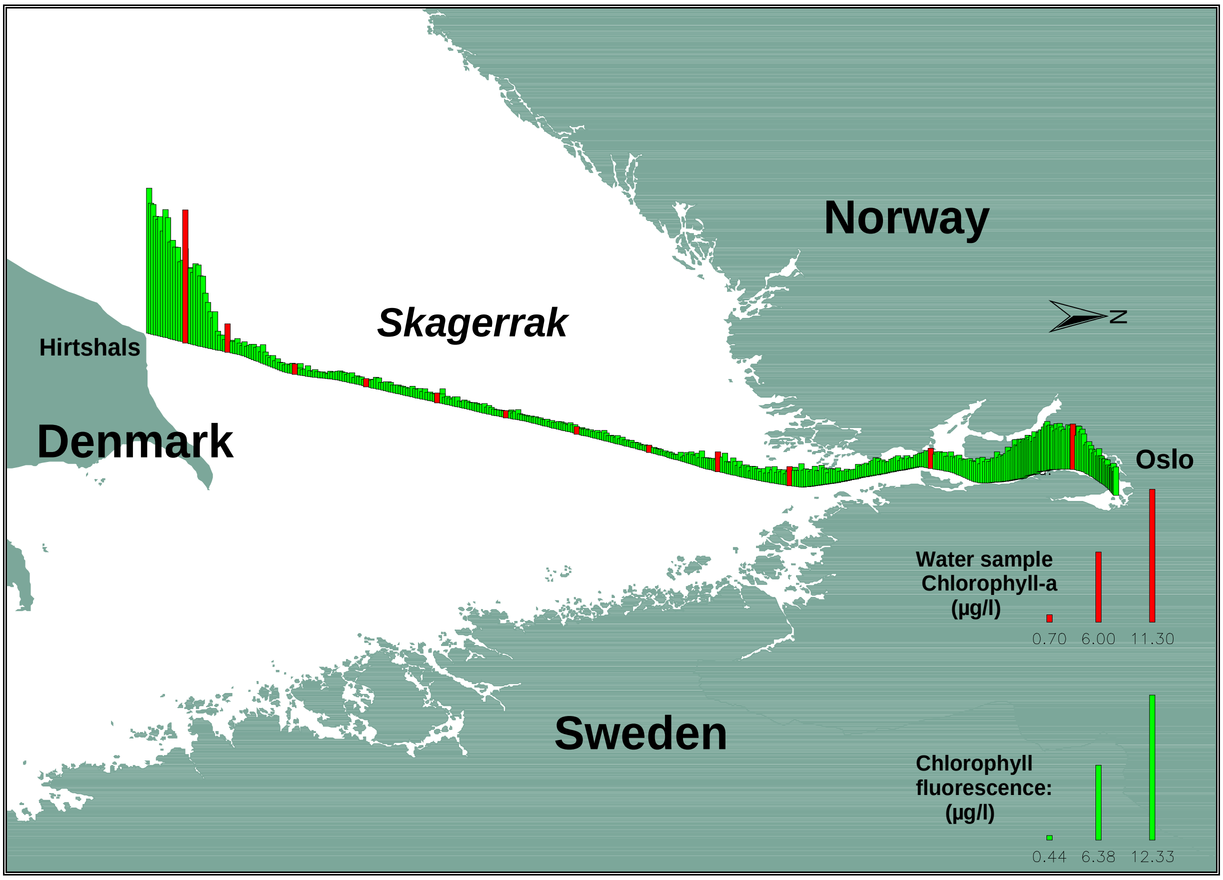

Figure 20. Observations of Chlorophyll fluorescence (µg/l) and Chlorophyll-a (µg/l) from 2-3.7.2002.

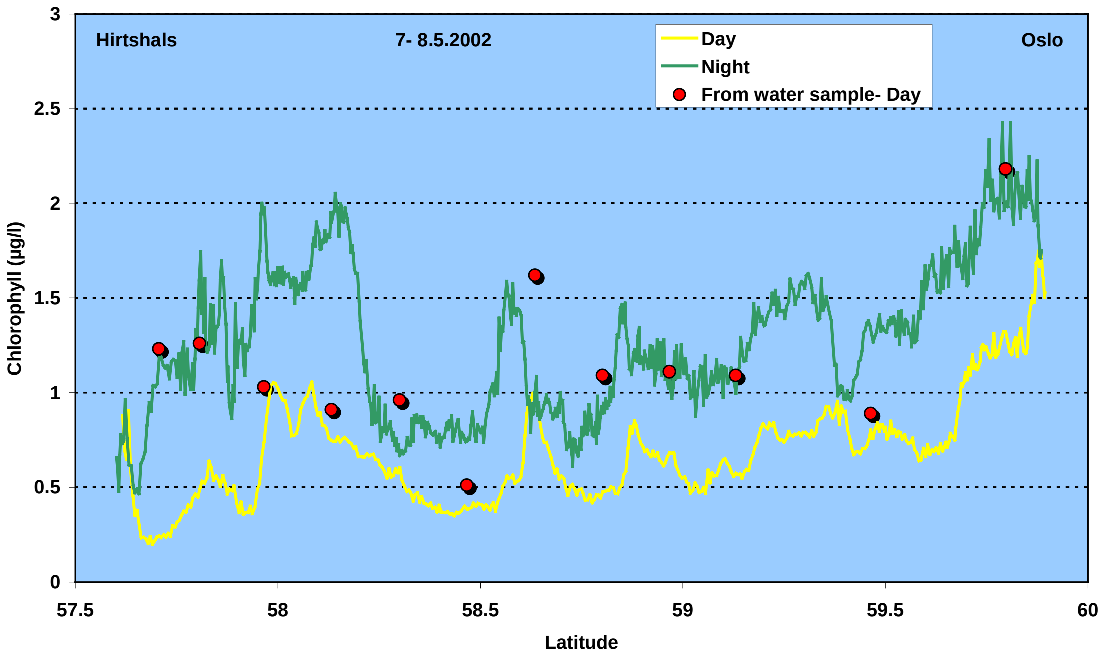

Figure 21. Chlorophyll fluorescence (sensors (night and day) and analysed (day)).

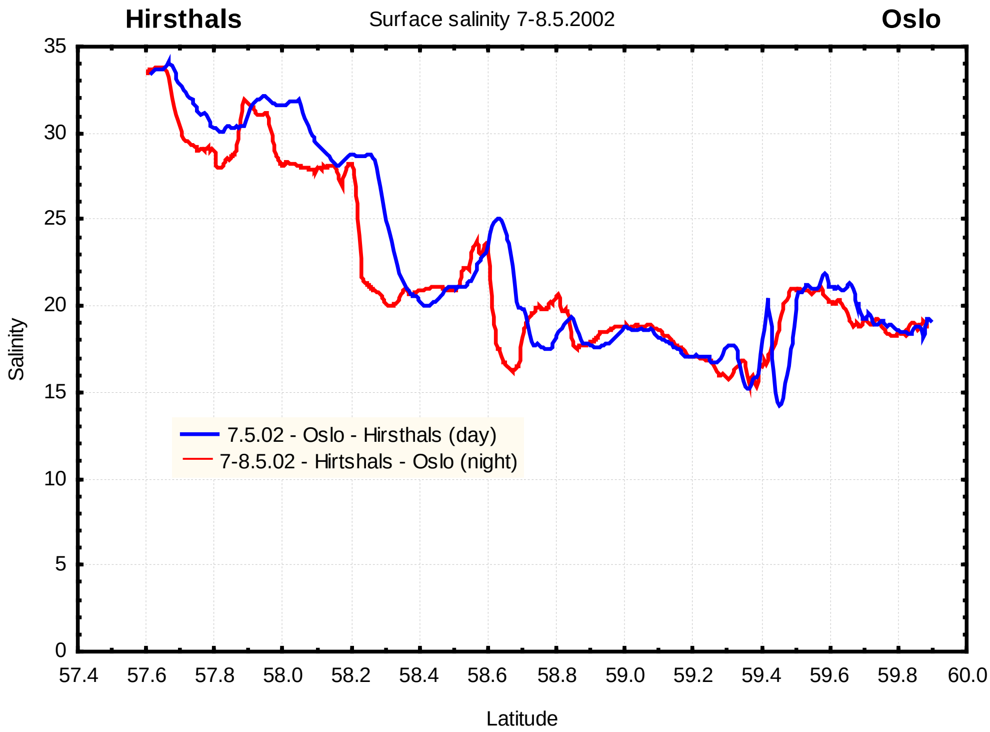

Figure 22. Surface salinity night and day between Oslo and Hirtshals. The main features are the same. A difference in salinity reflects slightly different tracks as well as variations in the position of fronts between the two cruises.

5.3 Salinity

The Seabird salinity sensors have been well tested and are generally reliable. The manufacturer recommends cleaning of the instrument once a month. We decided to test the system roughly by ignoring all cleaning procedures until May 2002 (Figure 23). The results were good, but the instrument was thereafter cleaned every second month. The second long time test carried out in July 2002 was equally satisfactory (Figure 24). The salinity in the water samples was analysed with a Guildline salinometer.

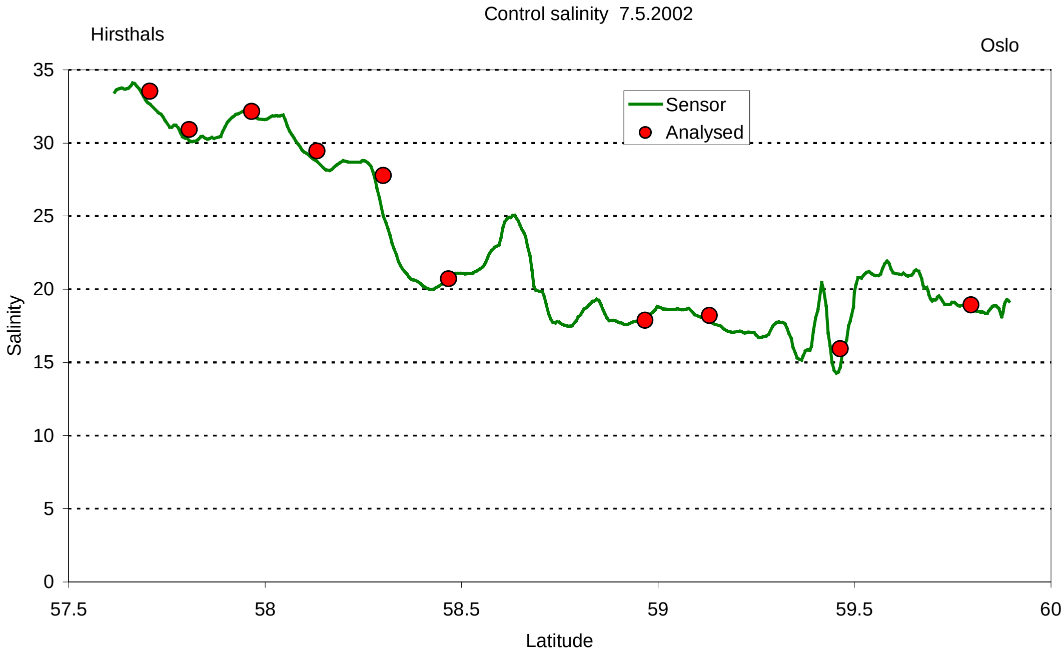

Figure 23. Salinity control 7.5.2002.

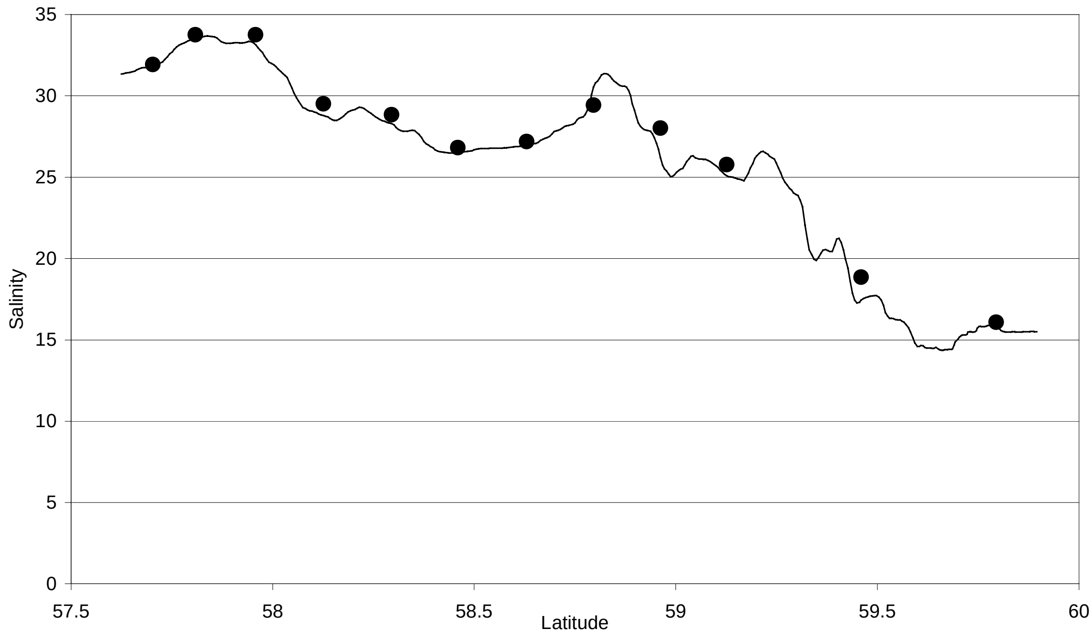

Figure 24. Salinity control 2.7.2002. Line = sensor, points=analyses.

6. Applications

6.1 Illustrate the potential of combined satellite and ship-sensor observations

The Color Festival system has been used as a support for other projects at NIVA, mainly in the process of sampling surface observations for interpretation of satellite images. These projects are still running and new projects have been started, where extensive use of the Color Festival observations is planned, together with other systems in Europe (the FerryBox- project).

So far the system has been used to find gradients during satellite passages in order to choose areas of interest for research vessels where more complicated measurements were necessary. The data from Color Festival during the research vessel cruise were then read continuously and the positions for observations were chosen in fronts or in water masses of special interest due to high turbidity or chlorophyll concentrations. Since the use of research vessels is planned several months in advance and the weather conditions can be unfavourable, the Color Festival system has been used to collect water and observations when the research vessel has been prevented from collecting samples. In this way the number of useful measurements has been extended and unfavourable weather conditions has become of less importance.

Samples and data from the Color Festival in 2001-2002 will be combined with the REVAMP and FerryBox programmes, both are EU-projects where NIVA participates as a Norwegian partner. The REVAMP project started in 2002, and its main objective is an Atlas of Chlorophyll for the North Sea, where the development of local algorithms for in situ chlorophyll (especially for turbid waters) and satellite remote sensing is central. The FerryBox project (started in 2003) will co-ordinate, test and compare several systems in Europe and will also use satellite observations. Both projects will contribute to the overall problem of monitoring and assess eutrophication in marine waters in Europe.

6.2 Early warning system for harmful algae

Programmes for monitoring of harmful algae in Norway cover the whole Norwegian Coast. Each week during the “season” for blooms, the Institute for Marine Research, the Norwegian Institute for Water Research and the OCEANOR analyses the situation and report results on Internet (http://algeinfo.imr.no/). Statens næringsmiddeltilsyn (SNT) analyses mussels weekly for consumption advice. Most of the sampling is close shore. Since spring 2002 weekly samples of algae from the Color Festival have been used in the programme. In fact, the first time sampling was done before this project started in March 2001 (**Figure 25**).

Today’s use of the Color Festival is more strategic. The standard number of stations is 17, and because there is a need for weekly updates, sampling is made each Tuesday. When the ship arrives in Oslo, the final decision on where to sample phytoplankton is made mainly based on the chlorophyll fluorescence during the cruise.

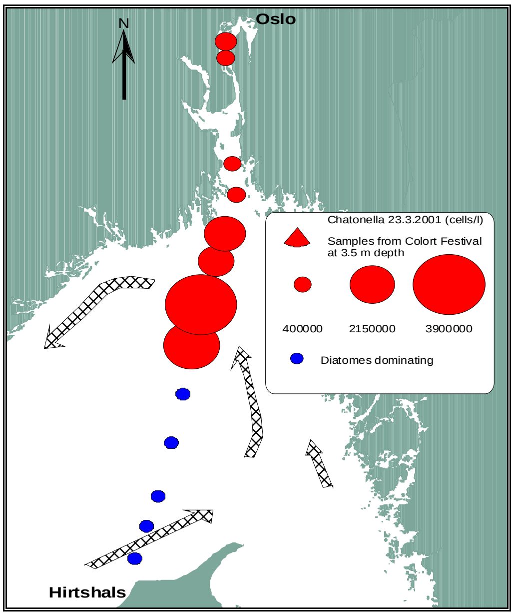

Figure 25. Example from a harmful algae bloom in the Skagerrak March 2001, samples from Color Festival.

6.3 Other applications

6.3.1 Observations of micro pollutants

The Color Festival system has been used in connection with the Elbe flooding in August 2002. There was concern about whether the pollution could reach Norway by the prevailing current system. The Norwegian Pollution Control Authority decided together with NIVA to use the Color Festival system for monitoring the transport of primary organochlorides (PCB, PAH). However, the system was not constructed for analyses of these compounds, so a test was run. Several components of both PCB and PAH were below detection level, so the system was not contaminated. This was, of course, not the case for heavy metals, where contamination was too extensive.

The Elbe water was not detected during August/September 2003. Dominating northerly winds and favourable currents kept the contaminated water close to the German Bight.

6.3.2 Observations of nutrients –environmental quality

Monitoring and assessments of eutrophication in marine waters are made by using analyses of nutrients and phytoplankton in surface waters (as well as other biological observations). The route of the Color Festival covers an area which is partly polluted with regard to this aspect. Both the Inner and Outer Oslofjord are covered, but also the area “down streams” polluted areas such as the Kattegat and the German Bight. Examples from the winter 2003 are presented in
Figure 26 –**Figure 27**, as well as average values of nitrate (+nitrite) from 4 samples per station **(Figure 28),** classified according to the Norwegian Classification System for Environmental Quality in Fjords and Coastal Areas. Based on concentration of nutrients, OSPAR uses a classification system in parts similar to the Norwegian system. Using ships of opportunity is in this context a powerful and non-expensive method.

The Color Festival system is now planned to be used regularly in the National Monitoring programme as well as the monitoring programme for the inner Oslofjord.

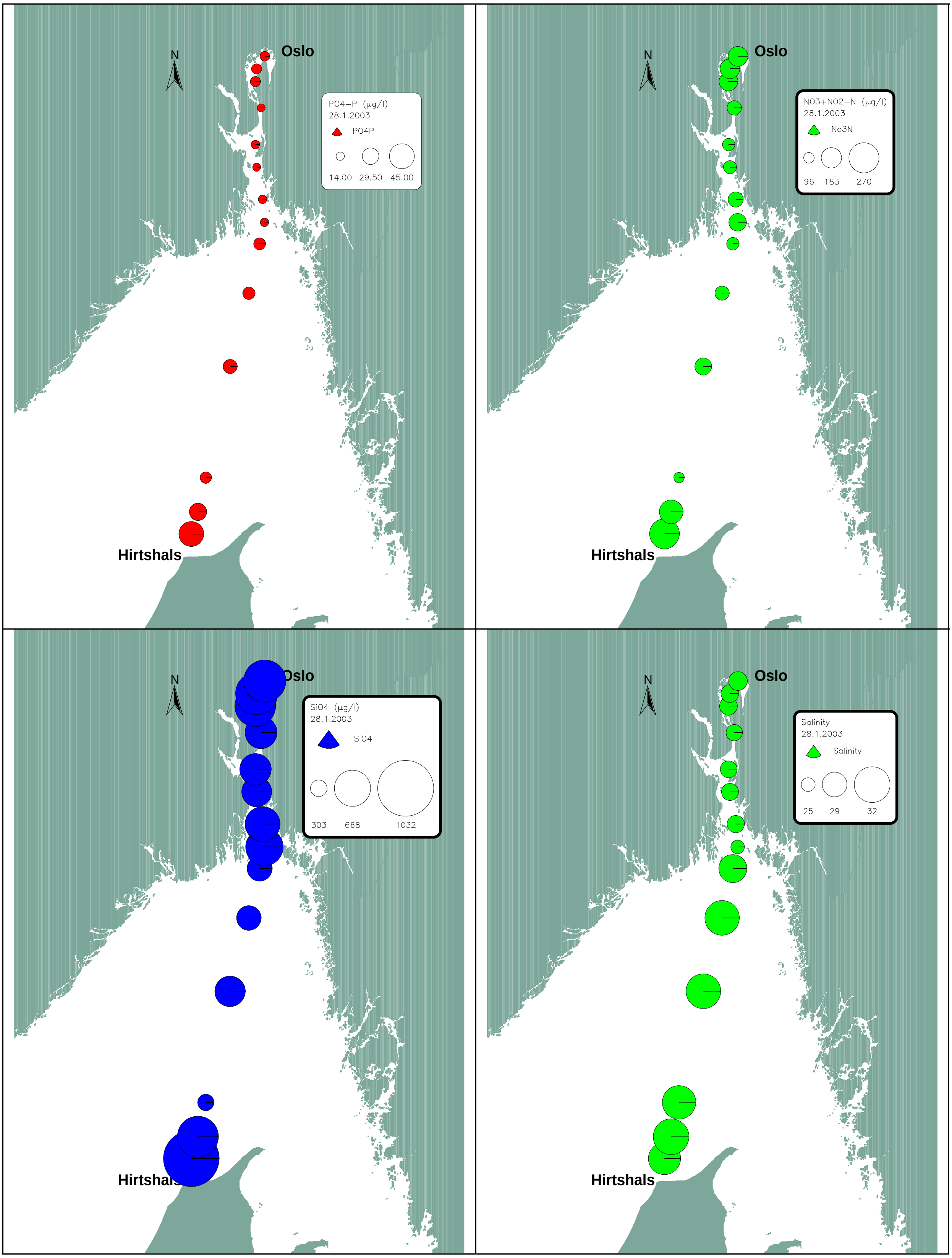

Figure 26. Observations of nutrients and salinity 28.1.2003.

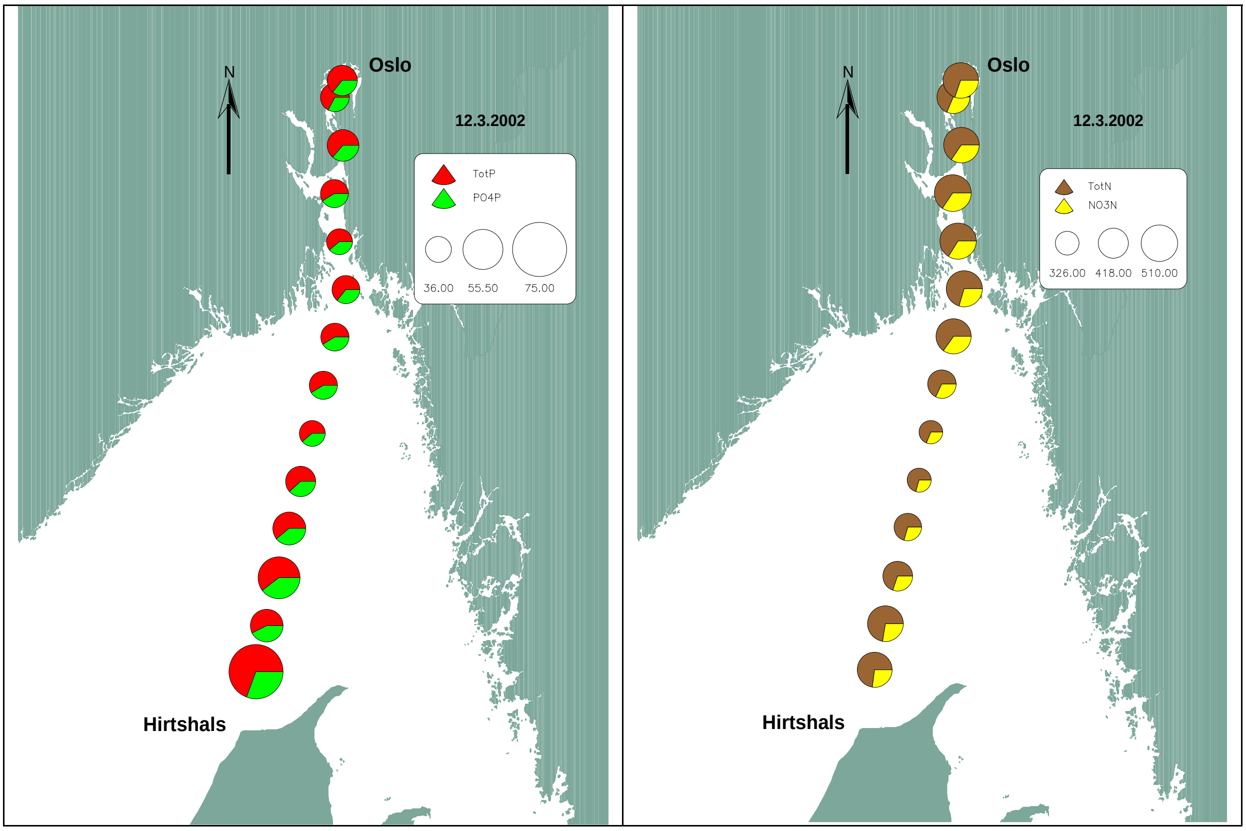

Figure 27. Nitrogen and phosphorous 12.3.2002.

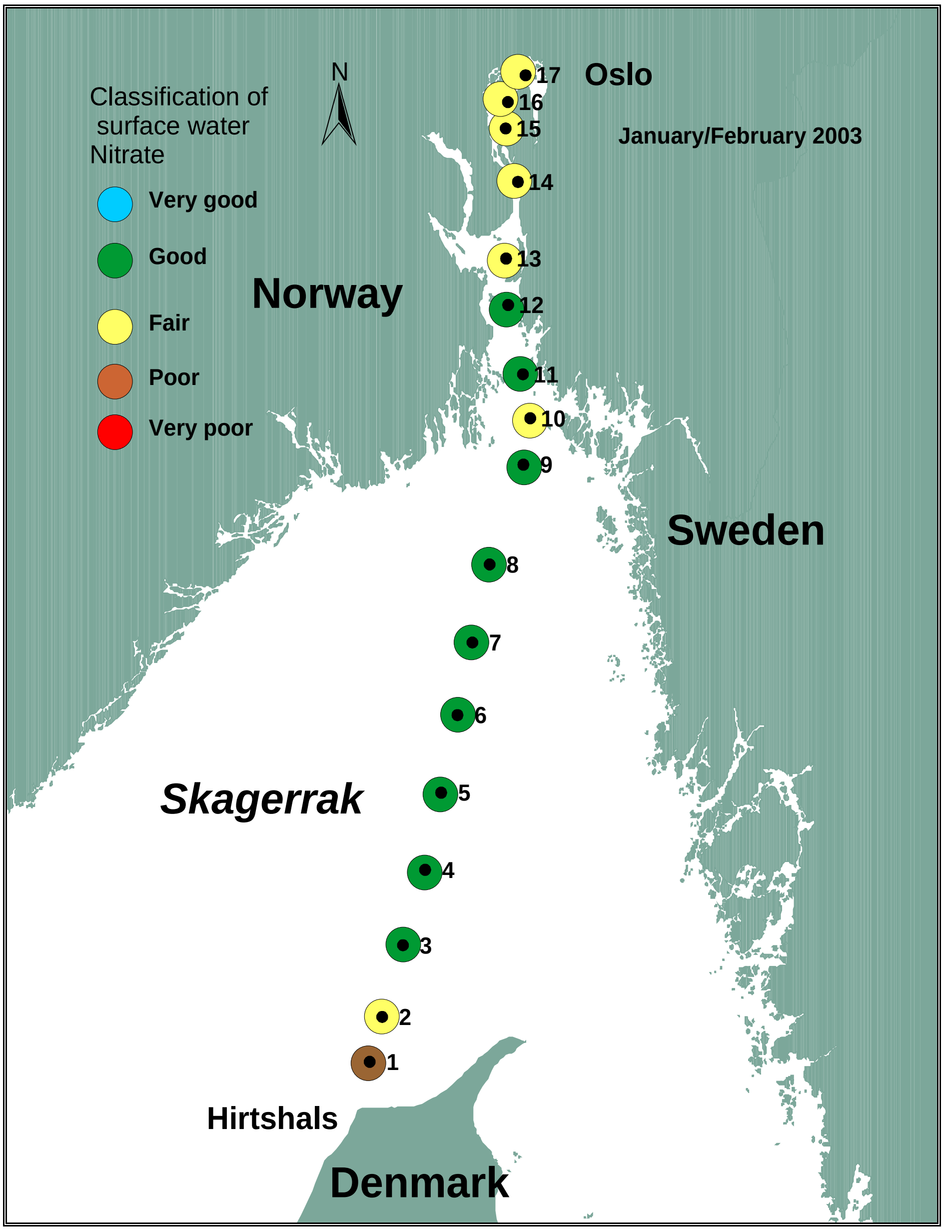

Figure 28. Example of classification of surface water according to the Norwegian classification system (Molvær et al, 1997).

6.3.3 Presentation of observations and further exploring of the Color Festival system

In the future observations from SOOP have many applications. One obvious task is temporal and geographical variation of the surface layer. Some examples of presentation are given in **Figure 29 - Figure 36**. Here monthly means and standard deviations of temperature, salinity, chlorophyll fluorescence and turbidity are shown for two months – July and October 2002. The observations are aggregated so each rectangle in the figures is the mid-point of latitude and longitude for the aggregated data, thus covering or representing half the distance between the rectangles. This is one possibility to aggregate data for climatic studies and variations (monthly) as well as a useful method for validation of numerical models. This simple presentation clearly indicates the problem with the different time scales in presentation of data. While temperature and salinity show relatively little variation of the monthly means for the two months, chlorophyll and turbidity have a standard deviation about the same size as the average. Monthly means are therefore not very well defined for the two parameters, at least not for July and October in 2002.

The aggregation of observations will affect the process of validating of numerical models. The selection of time scales will be important.

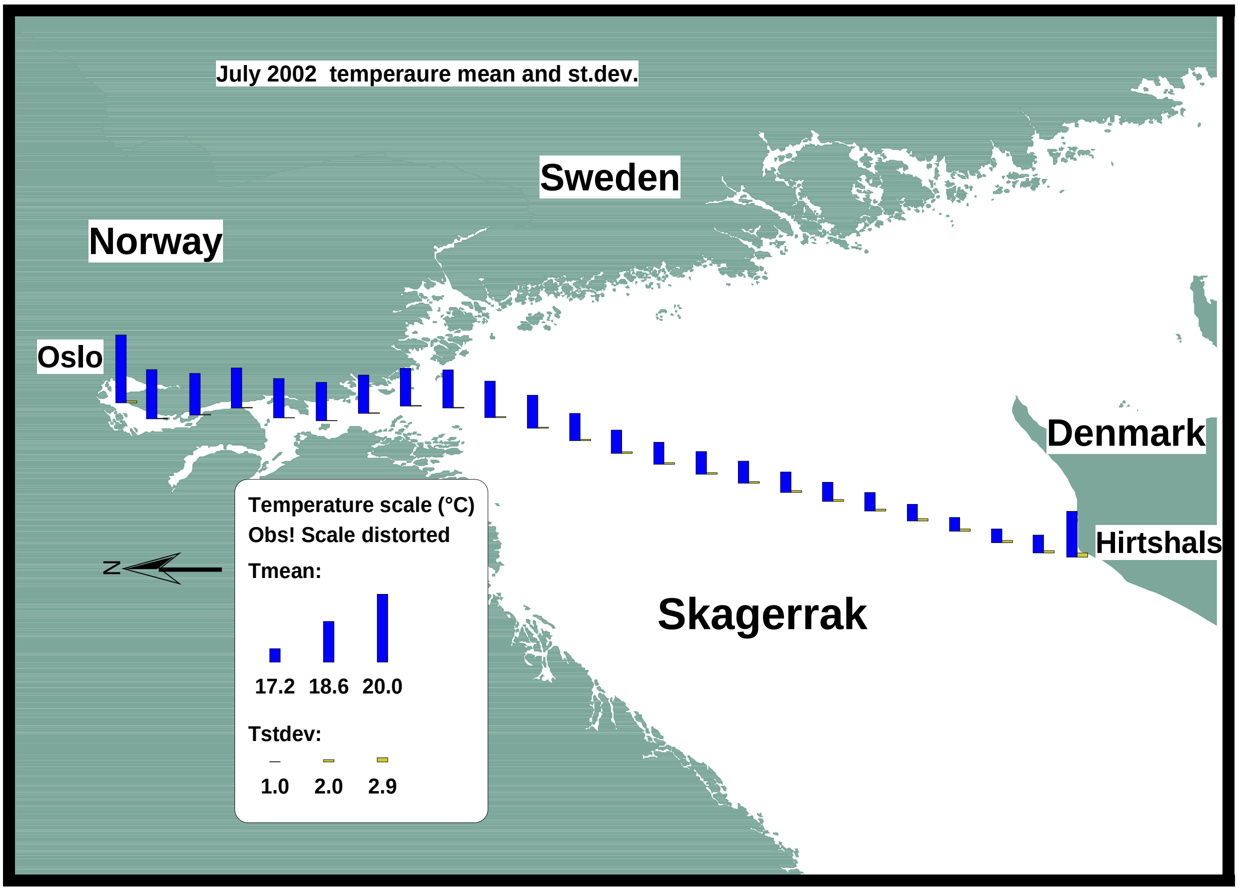

Figure 29. Temperature (mean and standard deviation) in July 2002.

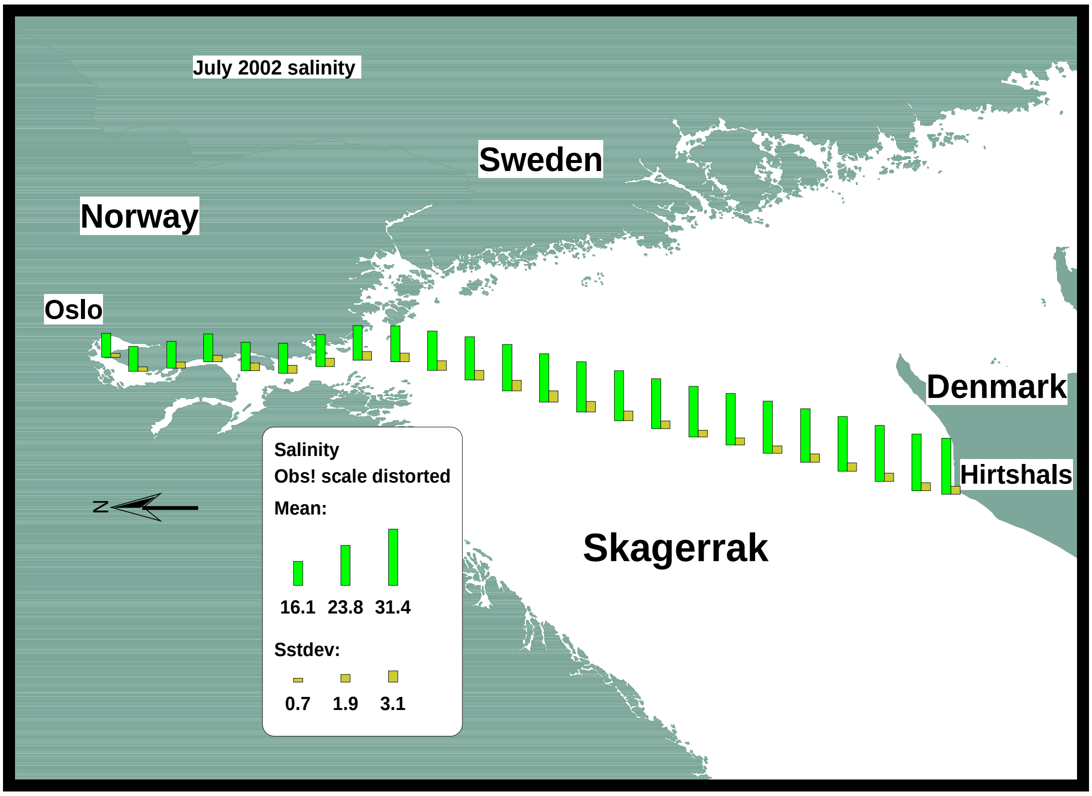

Figure 30. Salinity (mean and st.dev.) July 2002.

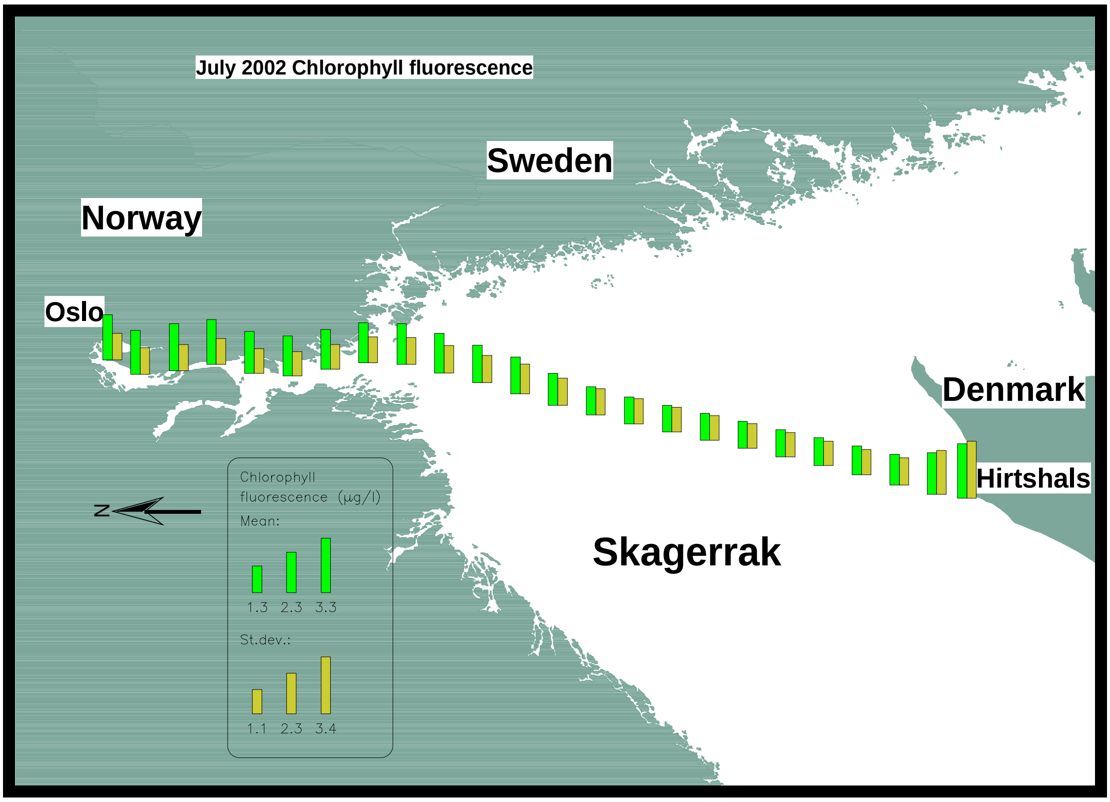

Figure 31. Chlorophyll fluorescence (µg/l, mean and st.dev.) July 2002.

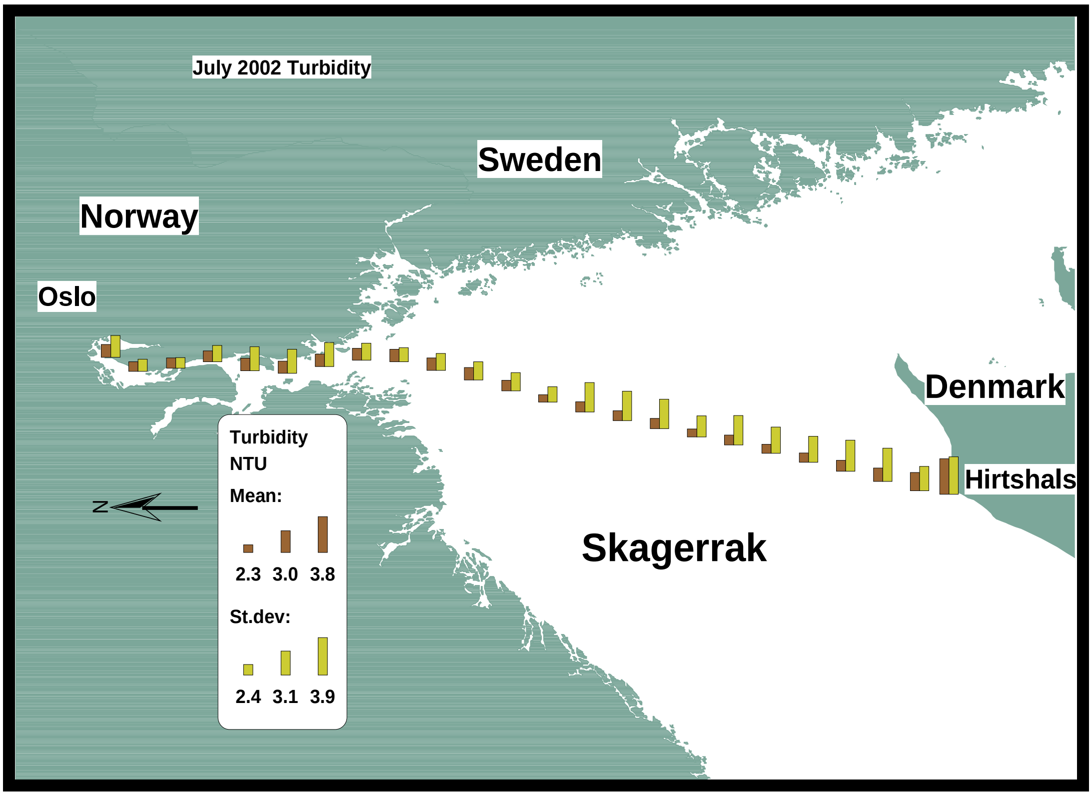

Figure 32. Turbidity (NTU or FTU, mean and st.dev.) July 2002. (NTU and FTU are equal unites).

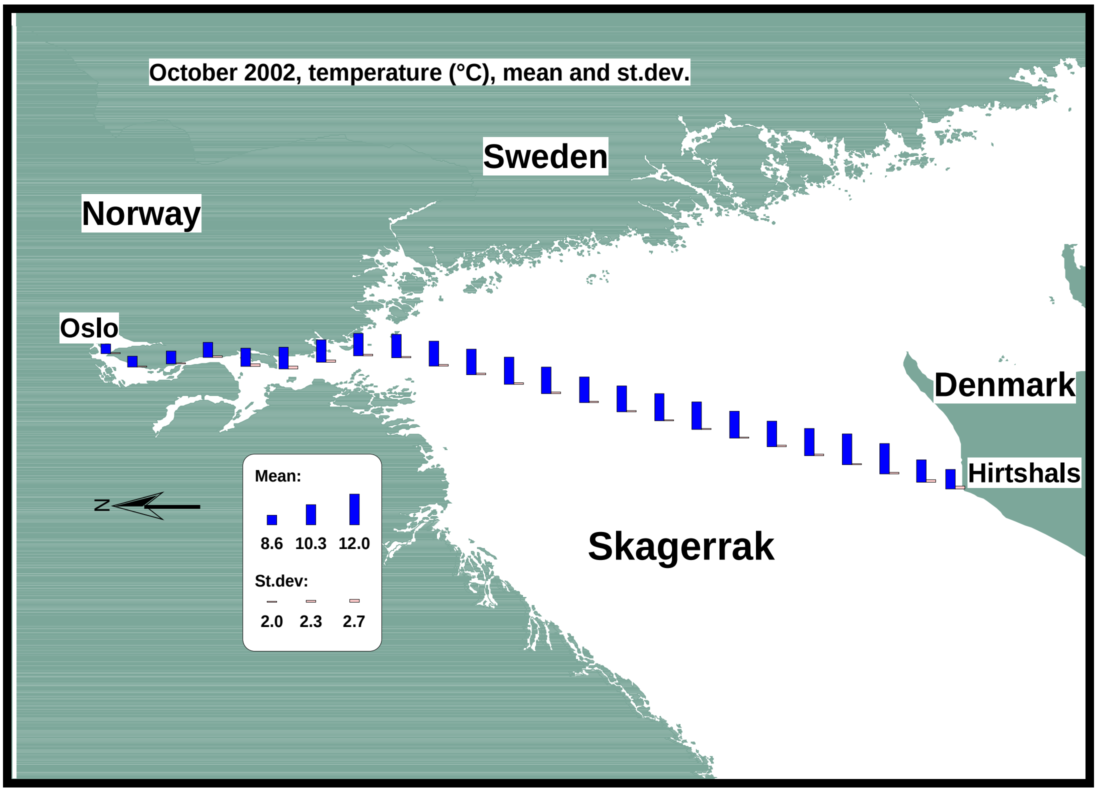

Figure 33. Temperature (°C), mean and st.dev. , October 2002.

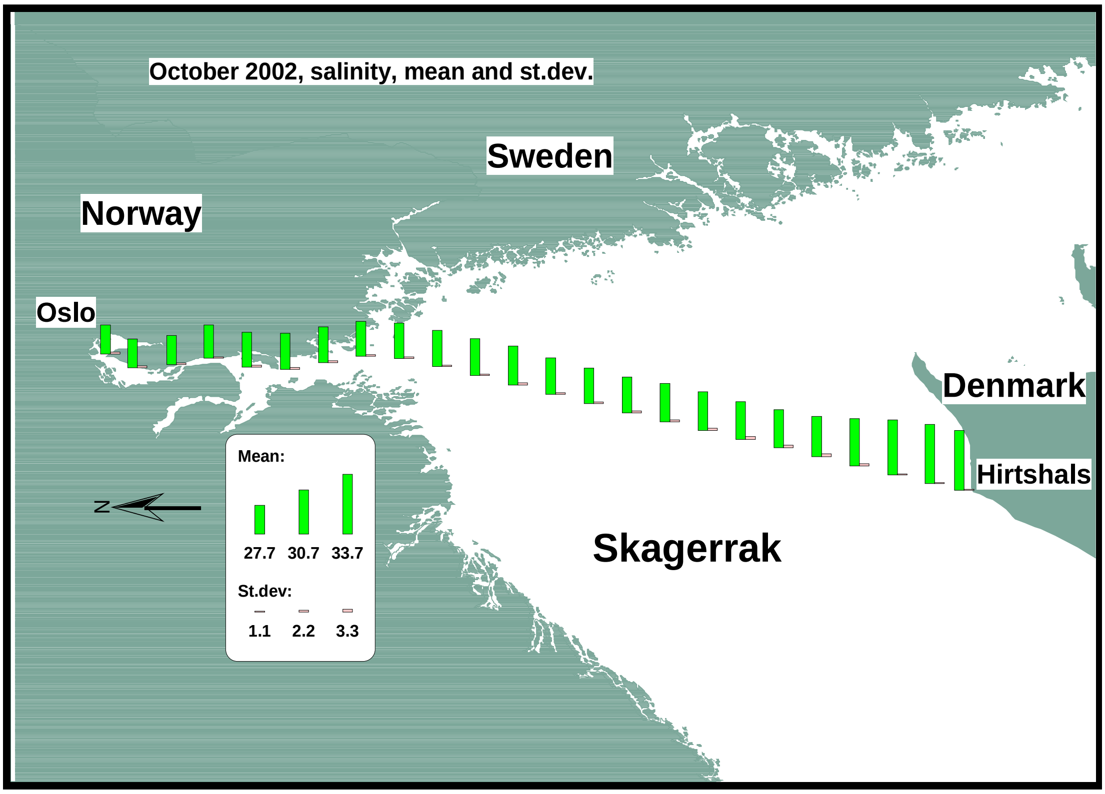

Figure 34. Salinity, mean and st.dev, October 2002.

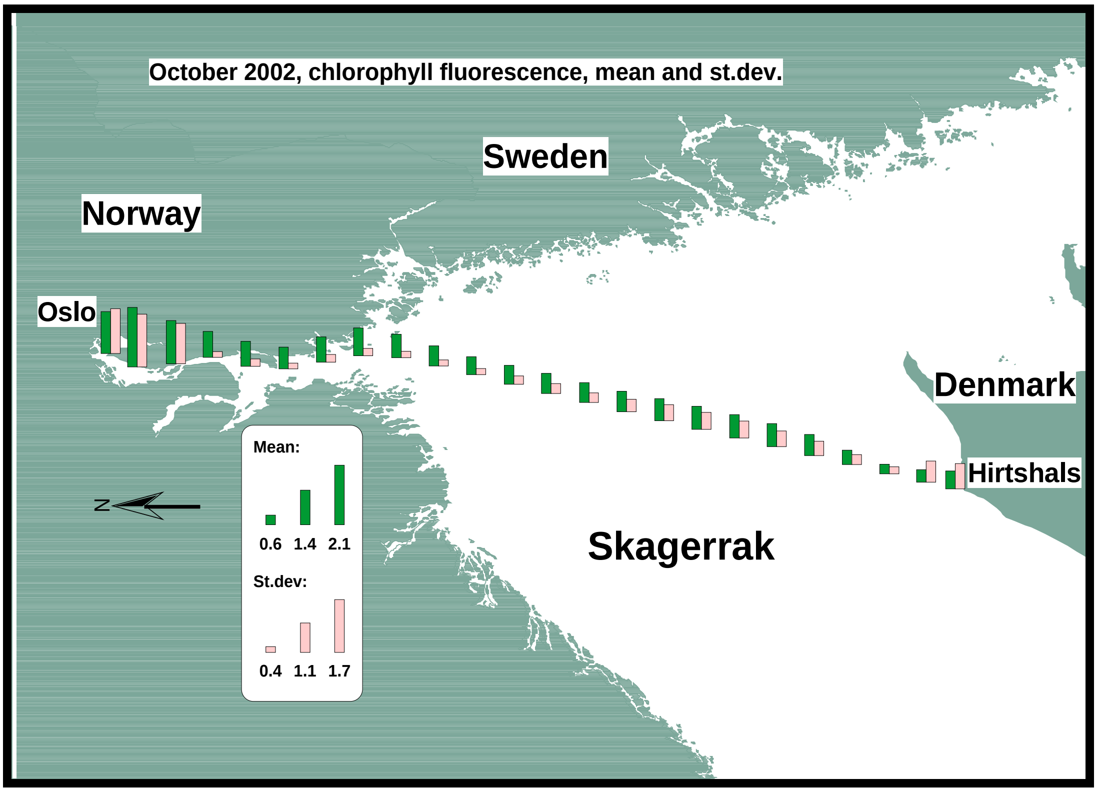

Figure 35. Chlorophyll fluorescence (µg/l), mean and st.dev, October 2002.

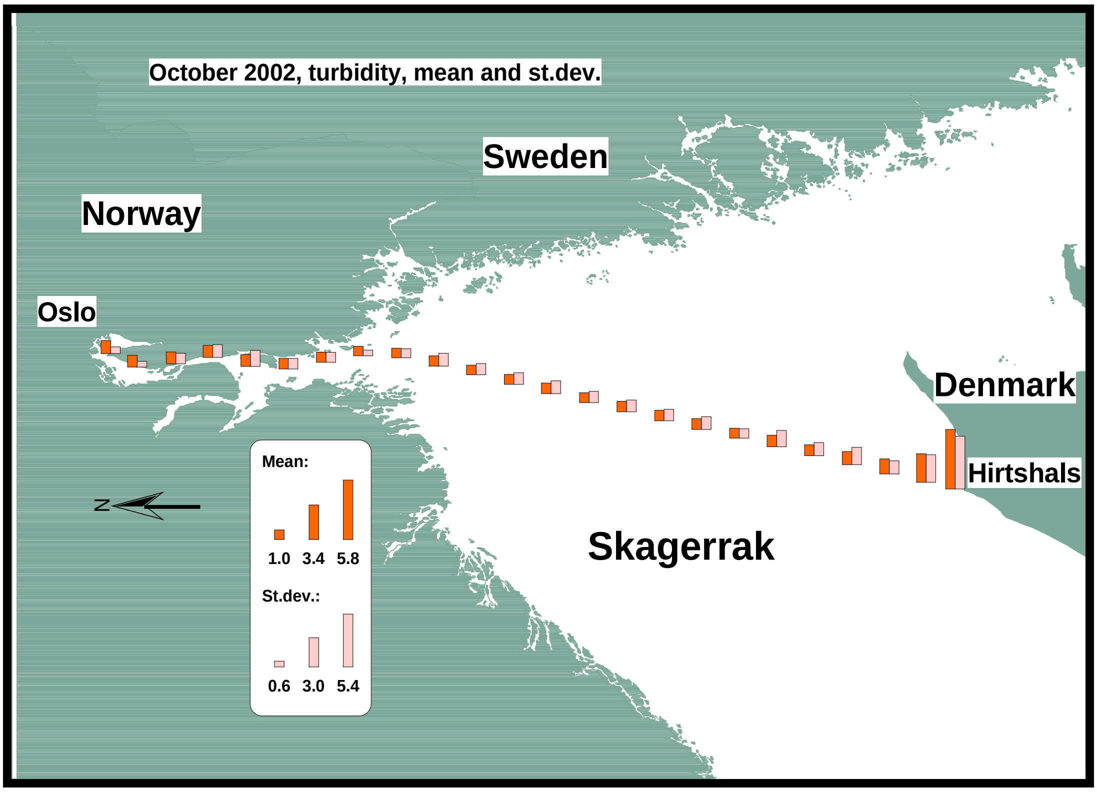

Figure 36. Turbidity (FTU), mean and st.dev, October 2002.

7. Conclusions

The project has achieved its main objectives, setting up and running a simple system on board the Color Festival, and presenting observation online over the Internet. Testing of the sensors has shown problems with turbidity, the other sensors seem to work nicely. However, improvement of the system is made in order to improve the performance of the turbidity sensor.

Servicing of the system is necessary. This should be about every fortnight for minor services, and monthly for more thoroughly examinations. This means cleaning the sensors and washing the sensor chambers each fortnight. Monthly during the production season (the summer season) the water inlet needs to be cleaned for fouling. The TSG (temperature/salinity sensor) is very reliable against fouling and needs only a minor service. However, in the long run this sensor should be serviced at least twice a year. The servicing interval can be prolonged if the system is equipped with a self-cleaning process, using flushing with freshwater and a weak solution of acid.

The Color Festival system has been used for the interpretation and validation of satellite images, but mainly in connection with other, still running, projects. The advantage of collecting water samples from "different" water masses is evident, especially when the usefulness of the samples for calibration require a clear sky. This has increased the number of images that can be used for these studies.

Regular samples are now taken about once a week during the algal production season for analyses of presence of harmful phytoplankton used in the national monitoring.

Other applications are in progress, as monitoring nutrients and phytoplankton in the inner Oslofjord and the Norwegian Coastal Environmental Monitoring Programme. The use of the Color Festival during the German flooding in August 2002 illustrated the possibility for catching extreme events without severe costs.

8. Litterature

Uehlinger, U., 1985. An *in situ* pulse light fluoremeter for chlorophyll determination as a monitor for vertical and horizontal phytoplankton distribution in lakes. Journal of Plankton Research. Vol. 7 no.5, 605-615.

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Molvær,J., Knitzen, J., Magnusson, J., Rygg, B., Skei, J., Sørensen, J., 1997. Classification of environmental quality in fjords and coastal waters. A guide. Norwegian Pollution Control Authority. Report nr. TA-1467/1997.