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Integration of oil detection functionality to FerryBox system

D1.2

WP1: Oil spill detection, monitoring, fate and distribution

Ship picture credit: shipspotting.com (Jukka Koskimies)

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Executive Summary

Our knowledge of the ocean is limited by our observational ability. To better understand and manage the oceans and the coastal systems, there is a clear need for environmental data of higher spatial and temporal resolution. Long-term operation of FerryBox systems has demonstrated the reliability and cost-effectiveness of such systems for observing the state of the ocean and seas over a wide range of temporal and spatial scales. There is great potential for data coverage using ferries and cargo ships of opportunity (SOOP) cruising on the same route on a regular basis, especially in coastal regions. It is fair to say that FerryBox systems have, reached reliability status. The installed systems can integrate data from water quality and meteorological sensors with GPS information into a data stream that is automatically transferred from ship to shore. Different applications reveal the usefulness of FerryBox measurements not only for monitoring purposes but for scientific questions as well.

There is still a particular lack of robust biogeochemical observations in the oceans and especially in the coastal regions with their high biological activity. Numerous promising technologies for better-automated measurements of different biologically relevant parameters are under development, or are even at a mature stage. FerryBoxes are ideal platforms to integrate such a sensor systems, even if they are in the development stage, as they offer a protected environment and easy access for maintenance and other issues.

In general, all FerryBox systems employ a quite similar basic design. The system consists of a water inlet from where the water is pumped into the measuring circuit containing multiple sensors. A basic system includes usually sensors for temperature, salinity, turbidity and chlorophyll-a fluorescence, and a GPS receiver for position control. Data is transmitted to shore via GSM/GPRS connection or satellite communication.

Marine Systems Institute at Tallinn University of Technology has maintained FerryBox on ferry M/S ROMANTIKA for over three years, between Riga-Stockholm and later Tallinn-Stockholm. During that time, many different parameters like temperature, salinity, chlorophyll-a etc. were continuously measured and the results could be seen online in real time. In the end of 2016 M/S ROMANTIKA was replaced with MS/ BALTIC QUEEN and the FerryBox system with some modification and oil detection capability, reinstalled to the ship. Data is represented on a webpage http://on-line.msi.ttu.ee/GRACEferry/.

Preliminary results of PAH measurements with FerryBox system on M/S BALTIC QUEEN on the route Tallinn-Stockholm-Tallinn (05.02.2017-14.02.2017) showed good data quality - PAH concentration varied between 0.014 µg/l and 0.093 µg/l. Differences in PAH concentrations between coastal areas and open sea could be seen.

1. Introduction to FerryBox systems on “ships of opportunity”

Our knowledge of the ocean is limited by our observational ability. To better understand and manage the oceans and the coastal systems, there is a clear need for environmental data of higher spatial and temporal resolution. The ocean continues to be severely under-sampled and gathering the required information in the field can prove costly. Long-term operation FerryBox systems have demonstrated the reliability and cost-effectiveness of such systems for observing the state of the ocean and seas over a wide range of temporal and spatial scales. [1]

Applying FerryBox systems has several advantages because (1) the measuring device is protected from damage caused by waves and currents, (2) biofouling can be more easily prevented by using inboard sensors, (3) energy supply is not limited as in the case of buoys, (4) maintenance during frequent and regular port calls is easy and cost-effective, (5) the costs of ship operation are omitted, (6) the measurements are continuous and yield spatial information along a transect. There is great potential for data coverage using ferries and cargo ships cruising the same route on a regular basis, especially in coastal regions. One obvious limitation of FerryBox systems is that they provide only data on surface water properties and, if necessary, have to be complemented with depth profiles obtained by conductivity, temperature and depth (CTD) measurements from research vessels or buoys. A disadvantage is also that the ship cannot stop during its cruise in order to perform more detailed onsite investigations and the dependency on the availability of voluntary ships in the area of interest, thirdly the operation relies on voluntary vessels that may be affected if the ship operator switches routes often at a short notice. This could be partly overcome if newly built ships would already be prepared for the installation of underway systems such as a FerryBox; this would not create significant additional costs in the construction phase. [1][2]

The notion of using SOOPs for scientific purposes has been utilized for quite a long time. Centuries ago, water temperature and certain meteorological parameters were recorded in logbooks. Modern SOOPs are rather more sophisticated in the way they can take measurements, including in the areas of chemistry and biology. For example, from 2003 to 2005, the European-funded multi-national collaborative FerryBox project was initiated to further develop and optimize the use of the so-called FerryBox systems for automated measurements and water sampling by utilizing ships of opportunity, e.g. merchant vessels and ferries. The core parameters measured were temperature, salinity, turbidity, and chlorophyll-a fluorescence on each route. Most of the involved institutes participate to the website of the European FerryBox community (http://www.FerryBox.org). Similar to the FerryBox activities in Europe, comparable projects are also under way in the US and Canada. [1][21]

It is fair to say that FerryBox systems have, reached reliability status. The installed systems can integrate data from water quality and meteorological sensors with GPS information into a data stream that is automatically transferred from ship to shore. Different applications reveal the usefulness of FerryBox measurements not only for monitoring purposes but for scientific questions as well. Due to large amounts of data, a suitable data management must be established, which includes sophisticated quality control in both real-time and delayed modes. Quality assessment, in particular, must be harmonized and standardized according to internationally accepted standards in order to make the data comparable and exchangeable. Nevertheless, it should be mentioned that even from automated systems such as the FerryBox, the quality of the data strongly depends on sufficient system maintenance and reliable quality data control on a regular basis. The possibilities to combine different transects and their partial overlap allow a comprehensive overview for a particular area and for a specific parameter. Furthermore, the linkage of such transect data with spatially distributed data from models or satellites can lead to synergistic effects in terms of validation or even improvement of the quality of products in the case of data assimilation. Data assimilation, in particular, needs sufficient spatial coverage, which is reached only in specific areas yet. [1]

There is still a particular lack of robust biogeochemical observations in the oceans and especially in the coastal regions with their high biological activity. Parameters such as dissolved oxygen, chlorophyll-a, pH, nutrients and turbidity are not observed to the same extent as parameters such as seawater salinity and temperature. Numerous promising technologies for better automated measurements of different biologically relevant parameters are under development, or are even at a mature stage. FerryBoxes are ideal platforms to integrate such sensor systems, even if they are in the development stage, as they offer a protected environment and easy access for maintenance and other issues. [1]

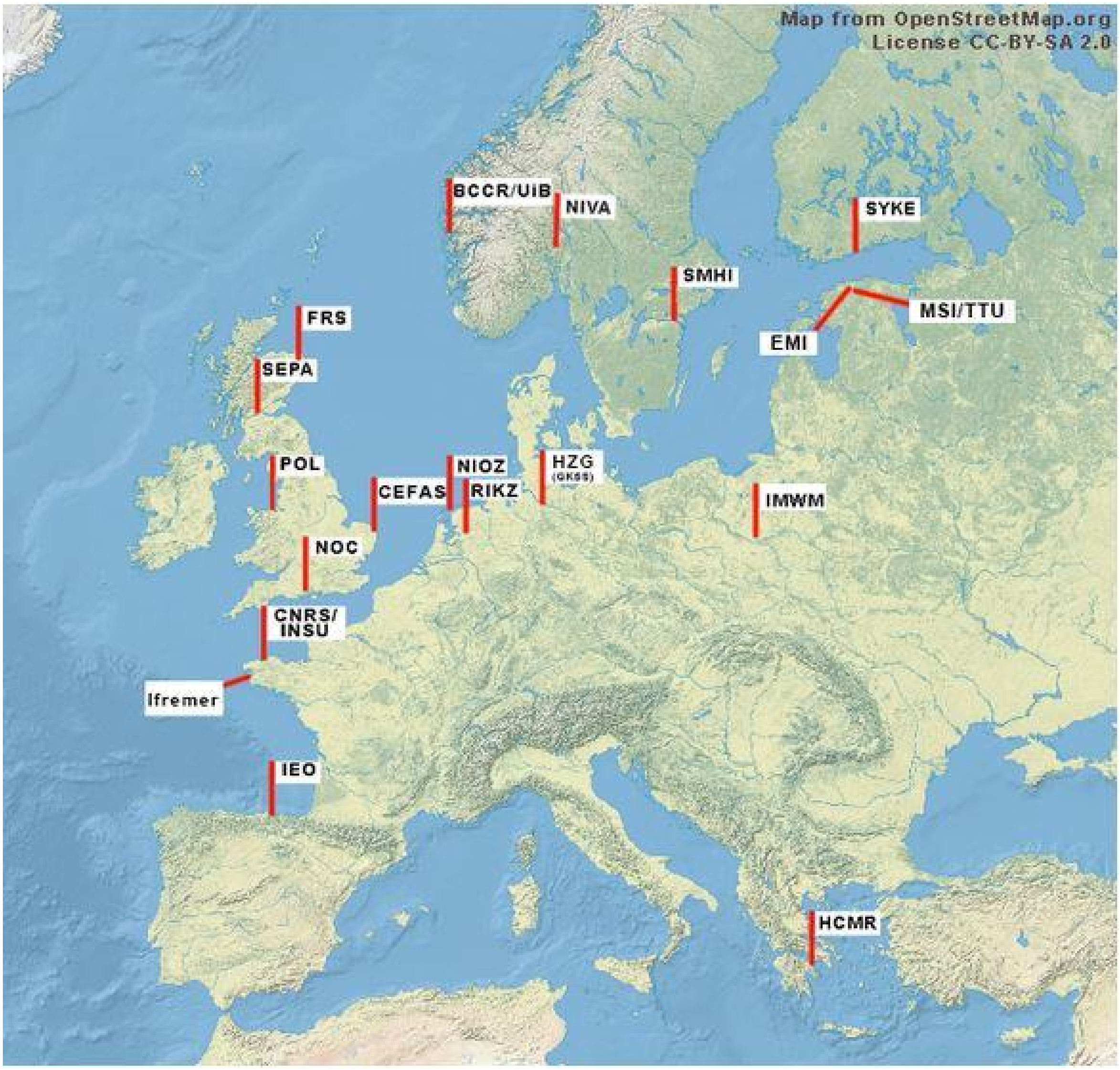


Figure 1 Main European institutions developing, operating or applying FerryBox systems [20]

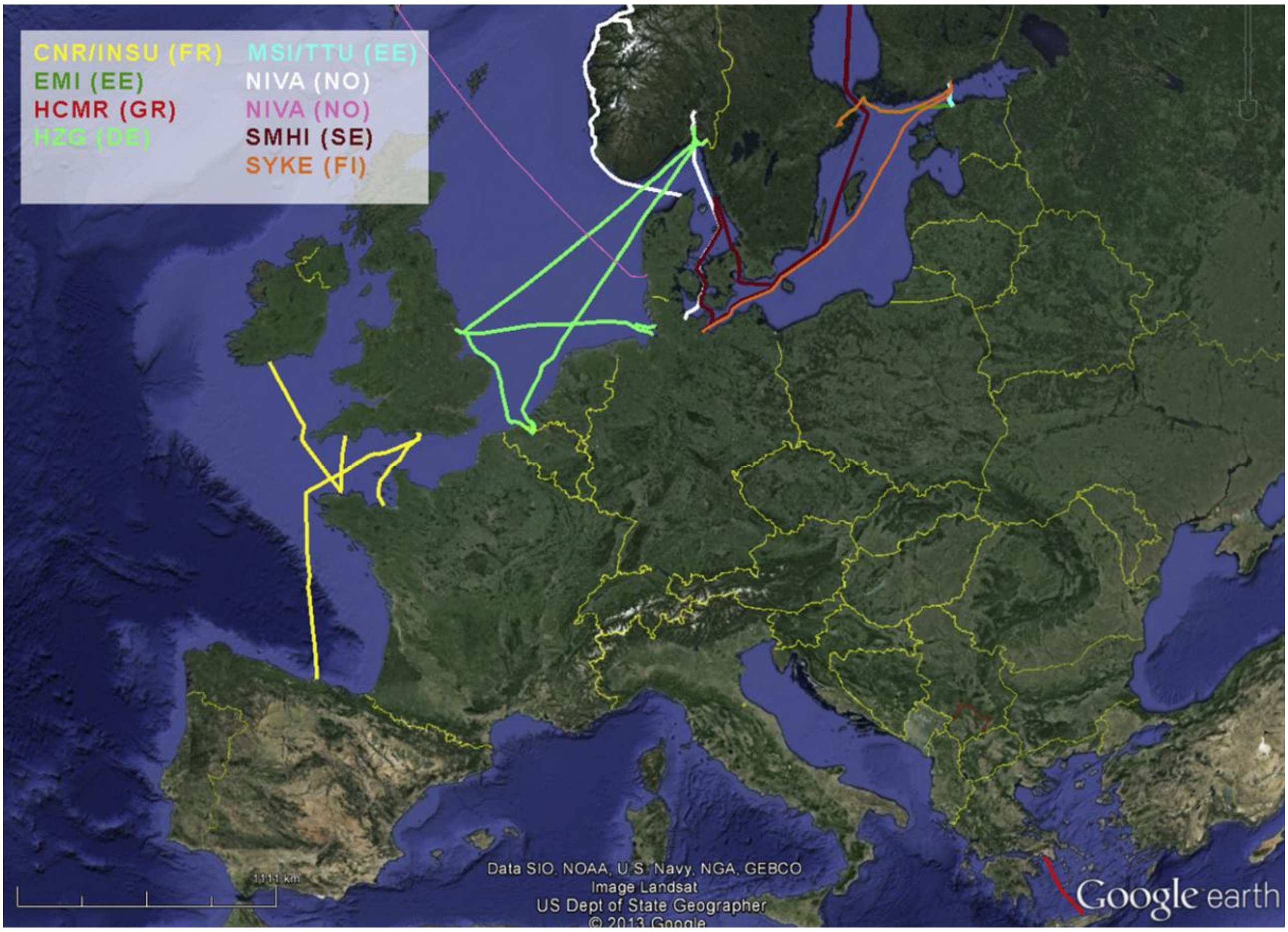


Figure 2 Some FerryBox routes in Europe [1]

1.1 Basic setup of FerryBox system

In general, all FerryBox systems employ a quite similar basic design. There could be differences in the design of the flow-through system, the degree of automation and biofouling prevention as well as the possibilities of supervision, data transfer and remote control. The system consists of a water inlet from where the water is pumped into the measuring circuit containing multiple sensors. This inlet may be positioned at the sea chest or on an extra valve in the hull of the ship, which could be but maybe not always is specially designed for the FerryBox's water inlet purpose. It is important to mention that the FerryBox should be positioned as close as possible to the water intake, that seawater should be less as possible influenced by ship’s environment, for instance, by long residence times in the sea chest or tubing. An optional debubbling unit removes air bubbles, which may enter the system mainly during rough seas. Coarse sand particles, which may enter into system in shallow harbours and which settle and tend to block the tubes, are removed as well by the debubbler. A basic system includes usually sensors for temperature, salinity, turbidity and chlorophyll-a fluorescence, and a GPS receiver for position control. Many systems also include an inline water sampler and additional sensors, e.g., for oxygen, pH, pCO2 or algal groups as well as meteorological instruments (air pressure, air temperature and wind). For reliable, unattended operation, a computer that also logs the data controls the system. Data is transmitted to shore via GSM/GPRS connection or satellite communication. In some systems, biofouling is prevented by automatic cleaning of the sensors with tap water, and by rinsing with acidified water or water containing a detergent after each cruise, which is controlled by the position of the vessel. A schematic diagram of a FerryBox system is shown in Fig. 3.

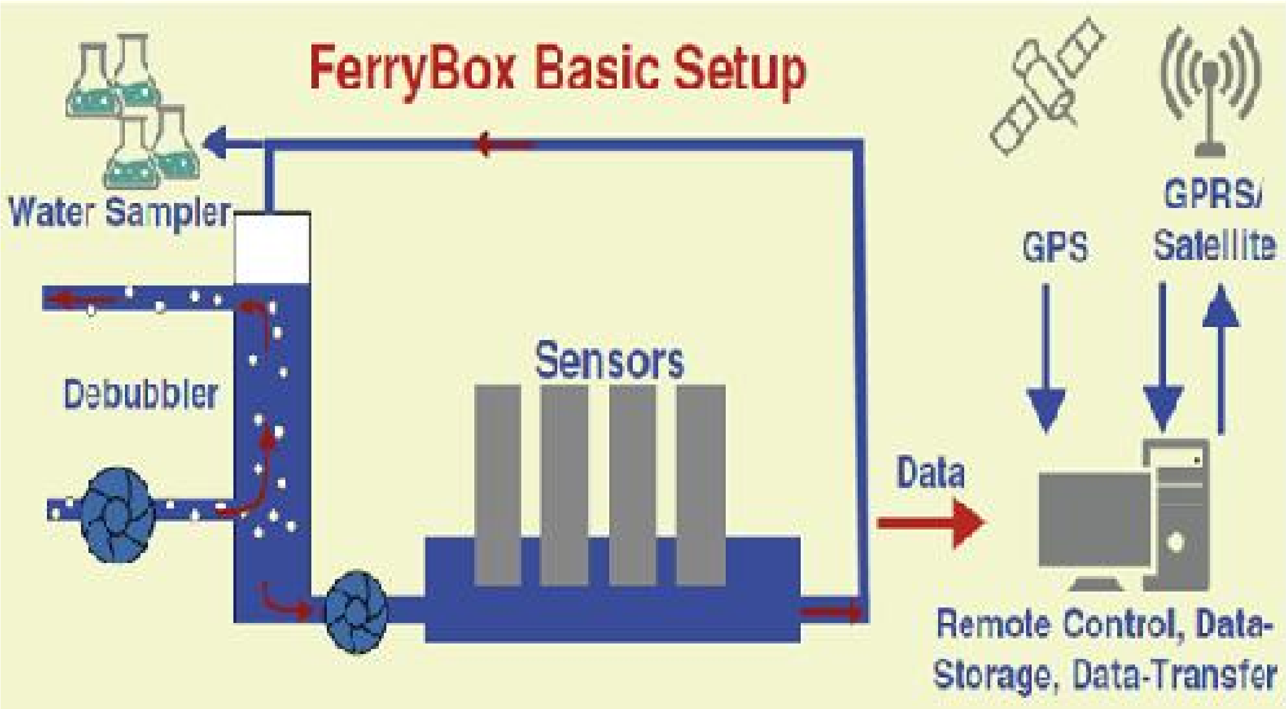


Figure 3 Basic Setup of a FerryBox (with optional debubbler) [1]

1.2 New technologies

Petersen [1] has given a good overview of new technologies compatible with FerryBox systems, as flow-through systems offer strong possibilities to extend the system of standard parameters with other, or even new, sensors as long as they are suitable for unattended operation over a longer time period. If appropriate new sensors are available for unattended use in SOOPs, the scope of marine research could widen considerably. This is also possible if these new instruments are not overly robust or are still in a prototype stage because they are operated in a protected environment within the vessel. Currently many new in-situ technologies under development are suitable for application in SOOPs. The range of available and reliable instruments, however, is still limited. Mature and suitable bio-geochemical sensors for unattended long-term operation for chlorophyll-a fluorescence, dissolved oxygen, pCO2 and pH (pH glass electrode with limited accuracy) are commercially available. Other instruments, such as chemical analysers for nutrients are offered as well; however, these sensors still suffer from long-term instabilities and tedious efforts are required for maintenance, including calibration and quality assessment.

Flow cytometry [3] may be a promising complementary method for obtaining information about the community structure of algae, including pico- and nano-phytoplankton. Zubkov et al. [4] have demonstrated first applications in underway systems earlier, but there are no applications for unattended operation on a routine basis. The complexity of the system requires further technical developments for long-term unattended operations. For monitoring of algae species and in particular harmful algae bloom (HAB) taxa, cost effective monitoring methods are needed. Conventional methods, such as light microscopy at the species or genus level, require broad taxonomic expertise and are time-consuming.

New technology based on nucleic acid biosensors for the detection of microbial organisms, and molecular sensors have been introduced as novel technology for monitoring phytoplankton [5]. Diercks-Horn et al. [6] have described a semi-automated rRNA biosensor for the determination of up to fourteen target species for detecting HABs. Further development shall result in a fully automated system that includes filtration.

Another important parameter is primary production. This measurement is difficult to make with autonomous systems, but is quite important for the assessment of the ecosystem's functioning. Fluorescence induction techniques such as FRRF (Fast-Repetition-Rate-Fluorometry) provide an alternative to laboratory ^{14}C uptake methods obtaining seasonal and annual primary production estimates [7]. However, signals generated by in-situ FRR fluorescence can exhibit a strong taxonomic (adaptive) component [8]. This method has not yet been used in systems on a routine basis due to complications in data interpretation.

In addition to light conditions, the availability of nutrients controls the algae growth, thus nutrient data are another important biologically relevant parameter showing great gaps in operational monitoring. With the exception of nitrate, nutrients can only be measured with the required sensitivity in the ocean with wet-chemical analysers. Most commercially available nutrient analysers developed for laboratory use require substantial and consistent maintenance and are not optimized for long-term unattended operation. Promising new developments based on sequential injection analysis (SIA) that are optimized for long-term unattended operation with regular internal calibration checks [9] may be commercially available in the near future.

With regard to the inorganic carbonate system, a quantitative assessment of the impact of biology and mixing on sea surface pCO2 measurement of additional inorganic carbon parameters is of great interest. This will help to better understand the role of the ocean for the uptake and storage of anthropogenic CO2, as well as of the degree of acidification of the oceans. There are, meanwhile, different reliable pCO2 measuring systems on the market. With respect to understanding inorganic carbonate system dynamics in addition to pCO2, at least a second component of the carbonate system must be measured. The combination of measuring pCO2 and pH would be less helpful because pH and pCO2 are strongly anti-correlated with subsequent error propagation when calculating the other not directly measured parameters of the carbon system. In particular, data of either total alkalinity (TAlk) or total dissolved inorganic carbon (DIC) must be sampled in addition to high accurate data of pCO2 or pH. Currently, efforts are being made to develop high frequency, automated in situ carbon sensor technologies to determine TAlk or DIC. The first instruments already exist for the measurement of TAlk or DIC with the required accuracy and precision (±1 μmol kg^{-1}). Recently a combined automated instrument that is optimized for underway measurements that measure high precision pH (accuracy±0.003) and TAlk (accuracy ±1.1 μmol kg^{-1}) by spectrophotometric detection has been introduced (Aßmann, 2012; Aßmann et al., 2011). A similar instrument for underway measurements, but solely for alkalinity, has been described by Wang et al. [10].

A different issue, which could be investigated by means of SOOPs, is the steadily growing abundance of microplastics in the oceans [11]. The lipophilic character of these particles results in the high enrichment of, e.g., persistent organic pollutants (POPs) that can be subsequently ingested by marine biota. After development of suitable techniques, continuous sampling along fixed routes could be used to investigate this issue on a global scale.

Another alternative in using the particular absorbing characteristics of plastics is the use of the so-called passive samplers for monitoring waterborne POPs or other organic pollutants [12] by absorbing the investigated contaminants on special plastic materials. Such samplers could be used in flow-through systems such as FerryBoxes.

1.3 Application of FerryBox data

In traditional monitoring methods using research cruises, monitoring stations suffer from limited coverage in space and time. Transects regularly sampled by FerryBoxes offer new possibilities for data evaluation and can provide new insights into physical and ecological processes in the ocean. Petersen [1] has pointed out a few selected examples from FerryBox applications.

Short-term events and productivity

Bargeron et al. [13] and Petersen et al. [15] have demonstrated estimation of productivity derived from oxygen fluxes calculated from continuous oxygen measurements along the route. Such evaluations are only possible from regularly served routes with high-frequency time series at each sampling point along transect. The results also demonstrated the importance of capturing short-term events to completely assess the status of the marine environment. For example, the spring algal bloom contributed to a high amount of total primary productivity for the entire year even if it lasted only a few weeks. Such blooms cannot, or can only occasionally, be detected by conventional monitoring methods such as research cruises or other field campaigns. For example Petersen et al. [2] demonstrated that an unusual short-term freshwater intrusion in the southern North Sea could be detected only by daily transects of a FerryBox in this region. Also stationary platforms with sensors such as smart buoys or other permanent underwater stations could reveal this kind short-term event.

Combining with satellite data

In principle, ocean colour remote sensing offers the opportunity to obtain estimates of water quality parameters over large areas from optical active substances such as chlorophyll-a, suspended matter and yellow substances. However, in the coastal waters it is sometimes difficult to clearly distinguish between the different constituents, resulting in large uncertainties of the estimates. In addition, cloud coverage limits the availability of data. FerryBox data can be applied to validate remotely sensed data of chlorophyll-a [14]). On the other hand, satellite data can be used to broaden the observations of the transect-restricted FerryBox data. Through this approach, a synergistic effect of both data sources can be accomplished [15].

Process studies

Cyanobacteria blooms are a recurring problem in the Baltic Sea. Algae data are regularly collected with FerryBox systems as part of the monitoring program Alg@line. The spatial extension, duration, intensity and species composition of these blooms varies from year to year. Particularly in the Gulf of Finland, the amount and species of the algae have been monitored over several years. From this data, together with research cruises, it has been shown that the main yearly differences, in regard to bloom intensity and the species composition, are not only driven by light conditions and water temperature, but also depend on wind conditions which cause upwelling processes, subsequently controlling the availability as well as P/N-ratio of the nutrients [16][17]. Again, such a comprehensive ecosystem approach was only possible by regular FerryBox observations in combination with surveys, including CTD casts and biological analysis of water samples.

Data assimilation for modelling

It has been shown that SSS (sea surface salinity) and SST (sea surface temperature) data from FerryBoxes demonstrate the potential for operational use in data assimilation schemes [18]. The assimilation of FB data enhances the quality of state estimates with respect to both SST and SSS for example in the German Bight. The validation with other SST data (OSTIA) shows a good skill in the vicinity of Ferrybox transects. Currently, only surface data are assimilated. Particularly in the German Bight, strong tidal influences limit a reliable assimilation to the vicinity (±40 km around the track) of the applied transect [19] because the propagation of the assimilated transect data in the model is only representative close to track.

2. FerryBox system equipped with UV-fluorometer for real time oil detection functionality

The Baltic Sea, one of the largest bodies of brackish water in the world has increased probability for oil pollution due to high shipping activity. In particular, heavy maritime traffic of oil tankers causes risk of collision and grounding, but also illegal discharges from flushing of machinery systems or cargo tanks of vessels causes risks. Spatial distribution of detected oil spills show that they most probably occur on major ship routes (Fig 4 and Fig 5). As ferries and cruise ships, used as SOOPs, also use fairways, it is reasonable to monitor concentration of oil compounds on these routes.

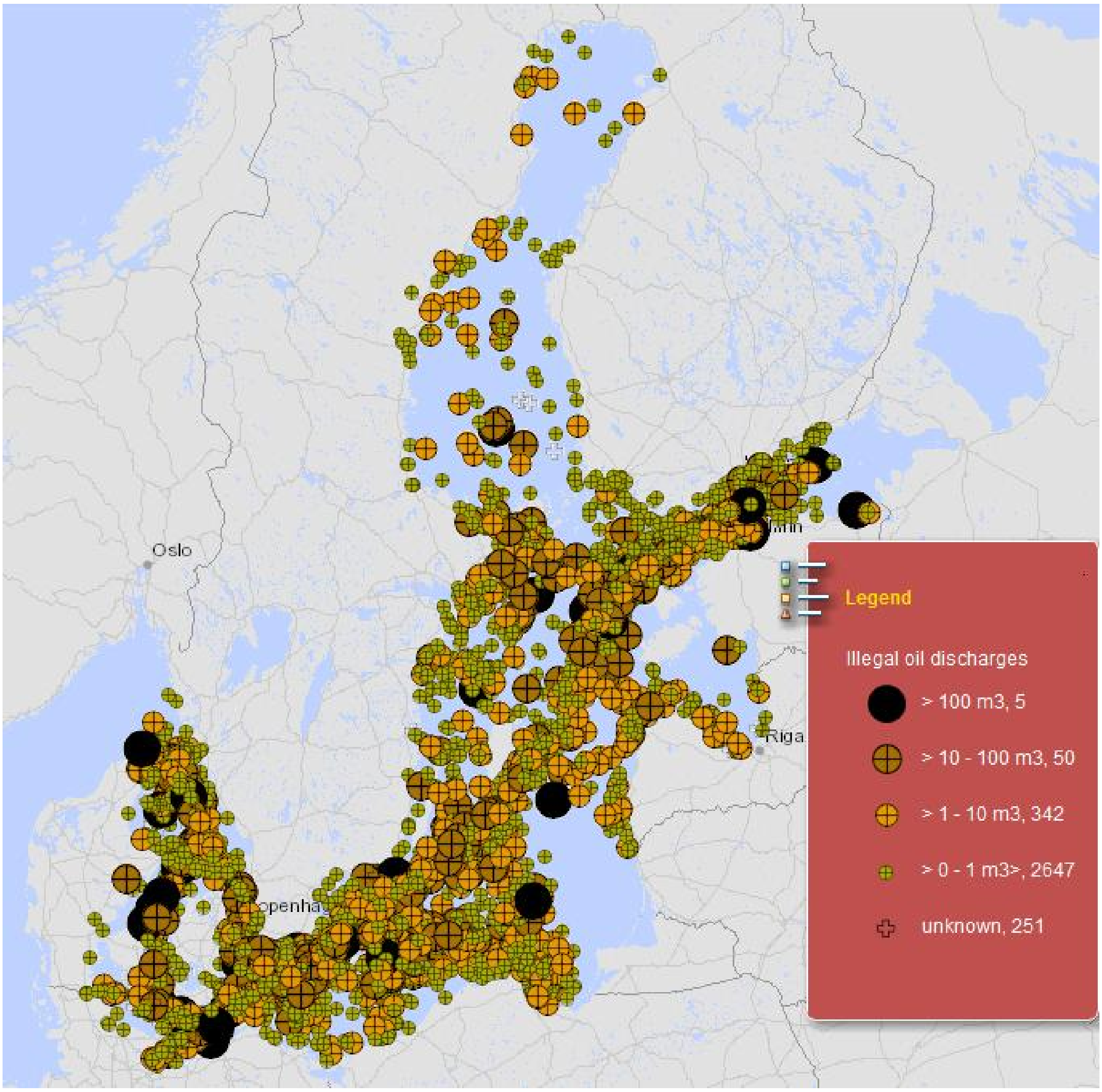


Figure 4 Points of information describing the location and size of illegal oil discharges observed during aerial surveillance flights by HELCOM Contracting Parties during 1998-2015.

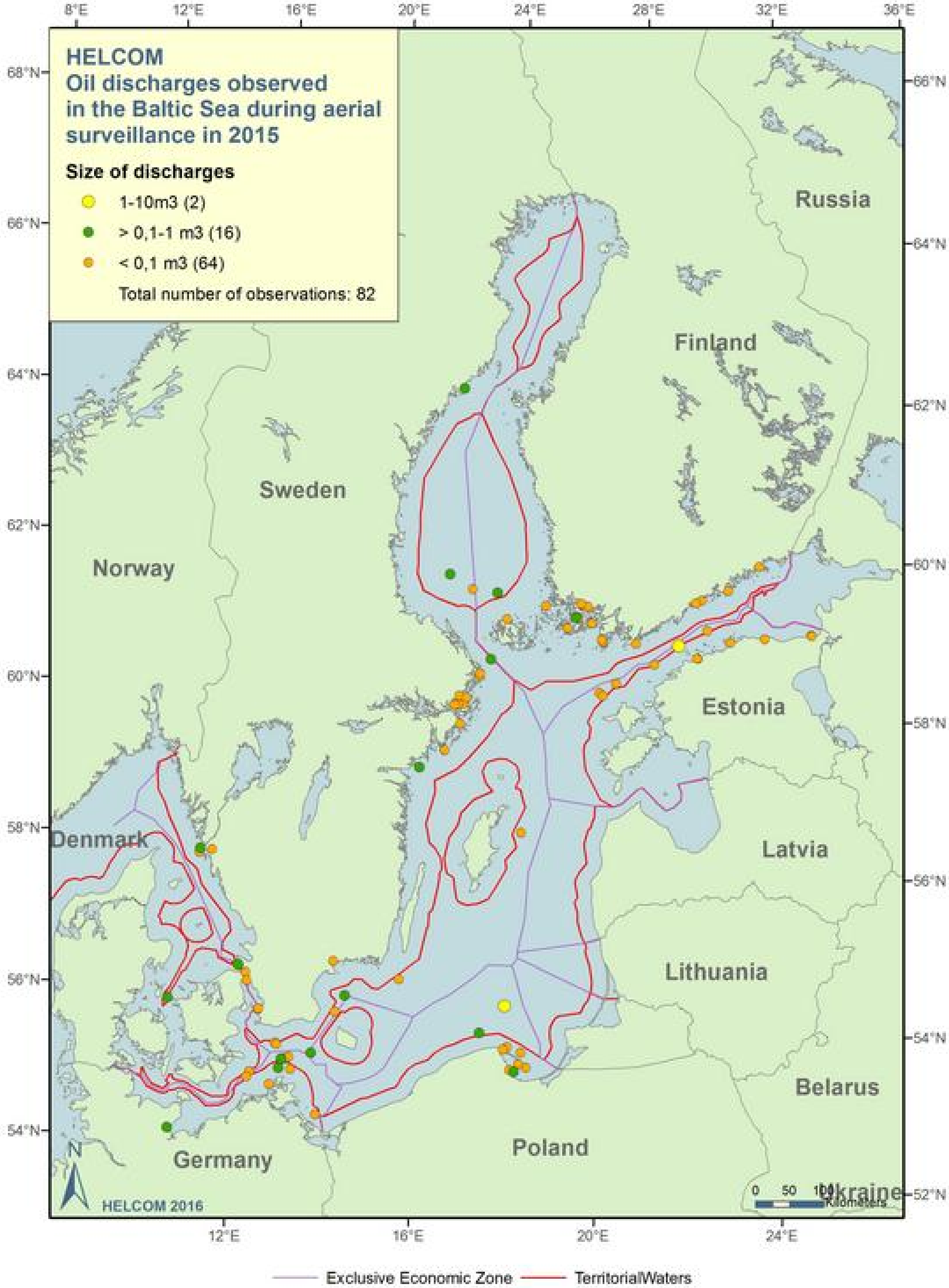


Figure 5 Oil discharges observed during aerial surveillance flights by HELCOM Contracting Parties during 2015

UV (Ultra-violet) fluorescence is considered to be highly sensitive, reasonably selective, simple, rapid and straightforward method to determine oil-based aromatic compounds in seawater, even in low concentrations. UV fluorescence oil detection method is used both in lab and on field, of course in lab conditions preciseness and repeatability is better. In-situ field operable UV fluorometers are nowadays compact, with low power consumption and with high sensitivity, down to 0.001 µg/L.

Marine Systems Institute at Tallinn University of Technology has worked with several FerryBox systems and compact system used on board M/S ROMANTIKA for over three years, between Riga-Stockholm and later Tallinn-Stockholm, serves as platform for current technological development. During M/S ROMANTICA time, many different parameters like temperature, salinity, turbidity, chlorophyll-a in terms of fluorescence etc. were continuously measured and the measurement results seen online through real time via web interface with high temporal resolution, 1 minute. Also new technologies and sensors like an oxygen optode, pCO2 sensor and phycocyanin sensors were tested. In addition some tests with oil sensor was performed on board M/S ROMANTIKA during project GEOILWATCH [22]. In the end of 2016 M/S ROMATIKA was rerouted to Riga – Stockholm route and the FerryBox system was needed to be removed from the ship. After some modifications, for both sensors setup and system, the FerryBox was installed on board M/S BALTIC QUEEN, replacing the M/S ROMANTIKA on Tallinn-Stockholm route.

2.1 Ferries M/S ROMANTIKA and M/S BALTIC QUEEN

M/S ROMANTIKA (Fig. 6) was built in 2002 in Finland, in Rauma Shipyards. Main dimensions (LOA x B x D) of the ferry are 193.8m x 29m x 6.5m, maximum speed 22 knots. Her initial route was Tallinn – Helsinki (4 years), then Tallinn – Stockholm (3 years), after that Stockholm – Riga (5 years) and since august 2014 she was rerouted again to Tallinn – Stockholm until December 2016 when she again went back to Stockholm – Riga route.

Figure 6 M/S ROMANTIKA (Tallink Group) Credit: shipspotting.com

M/S ROMANTIKA has carried an early version of FerryBox system on board almost since her maiden voyage, when she started on Tallinn – Helsinki route. Last system installed was already the third one. All these systems have been situated on the same place and have used the same connections (power supply, data transmission, water connections). All this gave MSI an excellent opportunity for smooth installation of the recent FerryBox (Fig. 7) system in June 2013. At that time, the ferry travelled on Riga – Stockholm route. The system, which included also web presentation solution, came operational in July 2013 for the project GESREG, data receiver Latvian Institute of Aquatic Ecology.

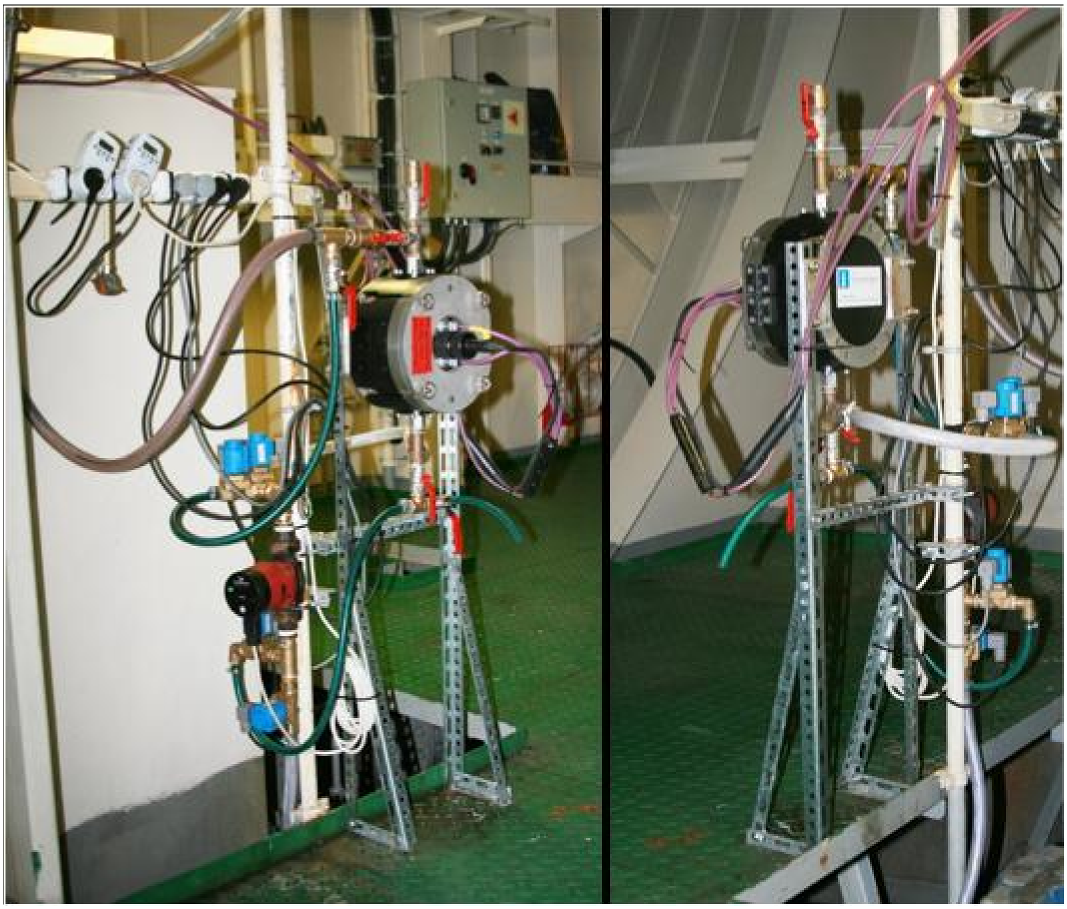


Figure 7 FerryBox system on board of M/S ROMANTIKA (Tallink Group) on deck one.

M/S BALTIC QUEEN (Fig. 8) was built in 2009 in Finland, in Rauma Shipyards. Main dimensions (LOA x B x D) of the ferry are 212,2m x 29m x 6.4m, maximum speed 24,5 knots. Her initial route was Tallinn – Stockholm (4 years), then Tallinn – Helsinki (3 years), since December 2016, she was rerouted again to Tallinn – Stockholm, replacing M/S ROMANTIKA.

Figure 8 M/S BALTIC QUEEN (Tallink Group) Credit: shipspotting.com

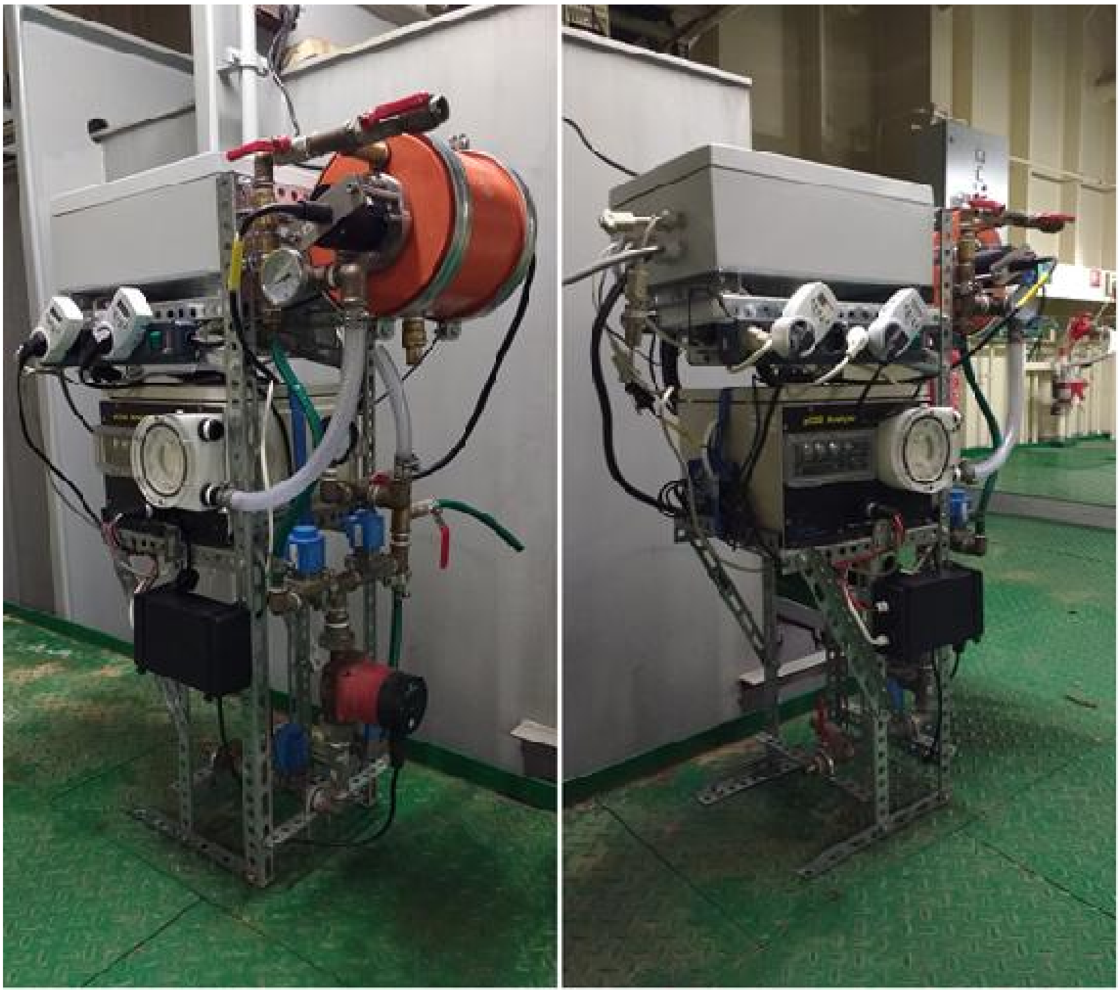


Figure 9 New, modified version of FerryBox system on board of M/S BALTIC QUEEN (Tallink Group) on deck one.

2.2 FerryBox installation

M/S ROMANTIKA and M/S BALTIC QUEEN are structurally quite similar in view of the FerryBox system. Both are located on deck one at the starboard side, in the same room with the ship's air conditioning (AC) system. There are several options for seawater connections in the aforementioned room. There are two different piping systems available: one of them is used for cooling AC system, another one is for firefighting system. Both systems use seawater, which is taken directly from sea via a sea chest (Fig. 10) from depth of 4-5 meters. The idea of using sea chest is to avoid closures caused by different obstacles (ice or garbage in seawater) and guarantee fluent water flow. It is especially vital, when facing fire on board. Both systems have been tested.

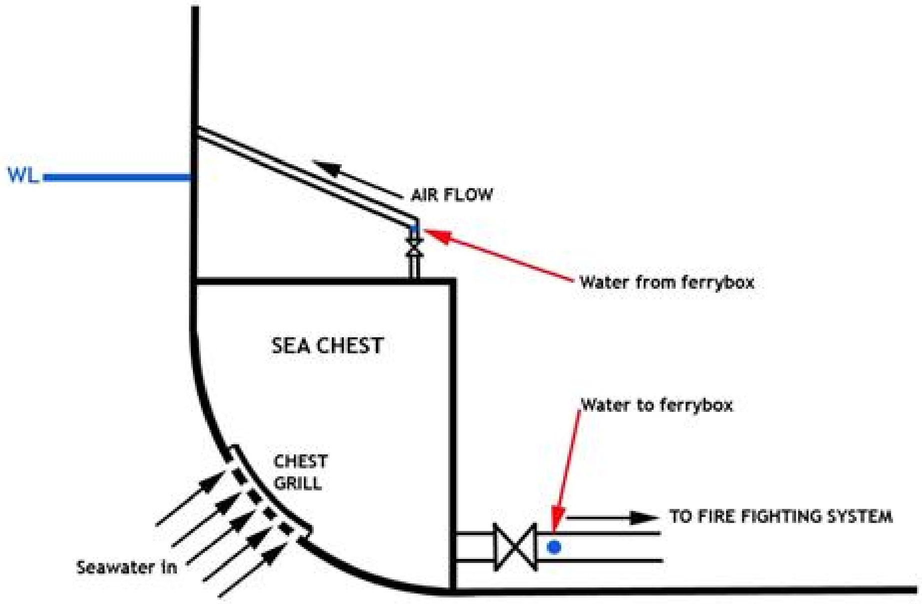


Figure 10 Starboard side of M/S ROMANTIKA and M/S BALTIC QUEEN and view to the sea chest, where the water to FerryBox system is taken from. Blue dots indicate seawater connections: lower one (connected to piping of firefighting system) is where water is taken from, upper one is where water is canalised (piping meant for removing air from sea chest).

For circulation, a pump/booster is required. The pump gets water directly from described piping of the firefighting system and forces it through the FerryBox, after that water is canalised overboard (see blue dots on Fig. 10). A timer controls working regime of the water pump. The pump has two regimes: ON, water circulates, FerryBox datalogger registers and condition the parameters from all installed, and OFF, no water flow. Regime OFF has the purpose to save the pump and extend its lifetime, e.g. there is no need for circulation during the time when the ship is berthed in harbour.

Different versions of water flow breakage have been tried and finally most optimum set up found. Keeping sensors clean is important. The problem is that when ship approaches the quay, mooring or leaving the harbour, fine sand and mud is resuspended into water column in the water that surrounds the ship. It is caused by propulsion system and bow thrusters. The aforementioned suspension will be sucked to the sea chest, where FerryBox gets its water. Thus, it is reasonable to cut off the water circulation and all the measurements, the act of which enables to extend time period between cleaning procedures and supports better data quality. It is vital in summer time, when the seawater is warmer and biologically active. There has been also mud filter installed but considering the amount of water passing the FerryBox, its efficiency was doubtful.

Another measure, that is taken for extending time period between maintenance procedures and keep sensors clean, is empting the FerryBox water chamber. Again, this procedure is executed when the ship is moored. The same water pump is utilized supported by four solenoid valves that reroute water circulation according to FerryBox regime (measuring mode/sleep mode). A timer also controls solenoid valves; timers for pump and solenoid valves are synchronized and work in pair.

2.3 Sensors installed in FerryBox systems

The FerryBox system can accommodate wide range of sensors, according to the task. However, the number of sensors at a time is limited with recording time, in other words datalogger should be able to connect to all sensors and collect data during data transfer interval, in this case during 1 minute.
On M/S ROMANTIKA temperature, conductivity, salinity, turbidity, chlorophyll-a, pCO_2 and phycocyanin were measured. Conductivity sensor was provided by Aanderaa Data Instruments (Norway). Optical sensor for turbidity and chlorophyll-a was measured with TRILUX was coming from Chelsea Instruments (UK). On top of aforementioned parameters, salinity was derived from conductivity and seawater temperature measured both by oxygen optode and conductivity sensors.
On M/S BALTIC QUEEN temperature, conductivity, turbidity, PAH and pCO_2 are measured.
For conductivity and temperature, High-Precision Pressure Level Transmitter Series 36 Xi W by KELLER (Switzerland) is used. Turbidity is measured with Seapoint Turbidity Meter by Seapoint Sensors, inc. (USA). UV-flouorometer for PAHs is coming from Chelsea Instruments (UK) and a The OceanPack™ pCO_2 analyzer by SubCtech (Germany).

Principle of functioning of the whole FerryBox and measuring procedure is following - sensors that are mounted to hatch or hatches (Fig. 12, 13, 14), which hermetically closes the FerryBox’s water chamber. Seawater passes through the chamber, where all the sensors register seawater parameters. The results will be collected and conditioned by datalogger (Fig.11), transferred to the ship bridge, added GPS location, time and sent via GSM/GPRS networks into on shore ftp-server.

Figure 11 Datalogger SmartGuard from Aanderaa Data Instruments on M/S ROMANTIKA, that collected all data from different sensors installed in FerryBox chamber. For data logging and transmission, additional sensors can be connected to the logger. [22]

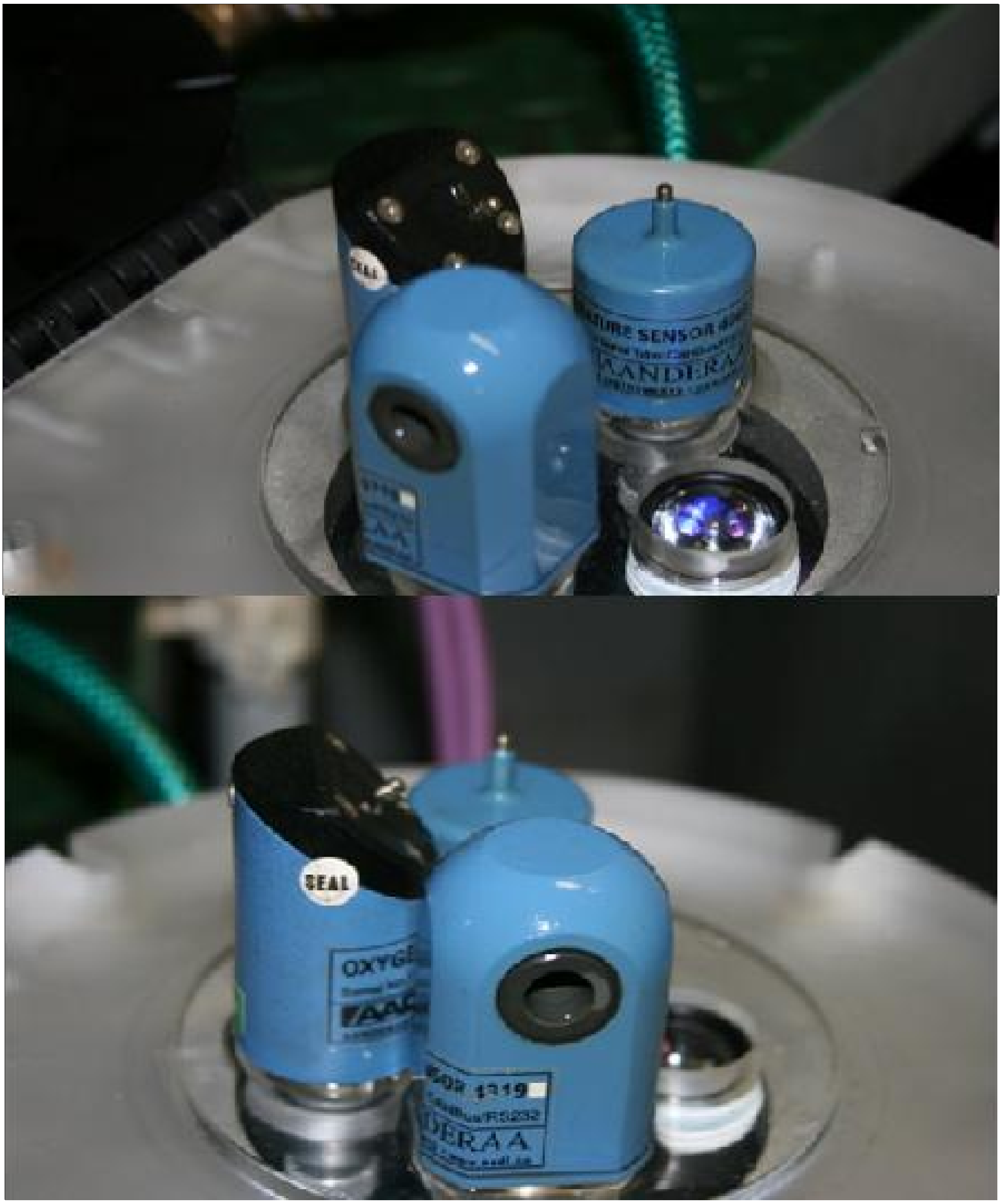


Figure 12 Sensors on FerryBox system aboard M/S ROMANTIKA, in this case temperature, oxygen, conductivity, turbidity/chlorofyll-a/phycocyanin. [22]

Figure 13 Sensors on FerryBox system aboard M/S BALTIC QUEEN. In the upper picture UviLux sensor for PAH detection and on the lower for conductivity and temperature, 36 Xi W by KELLER (left) and Seapoint Turbidity Meter (right).

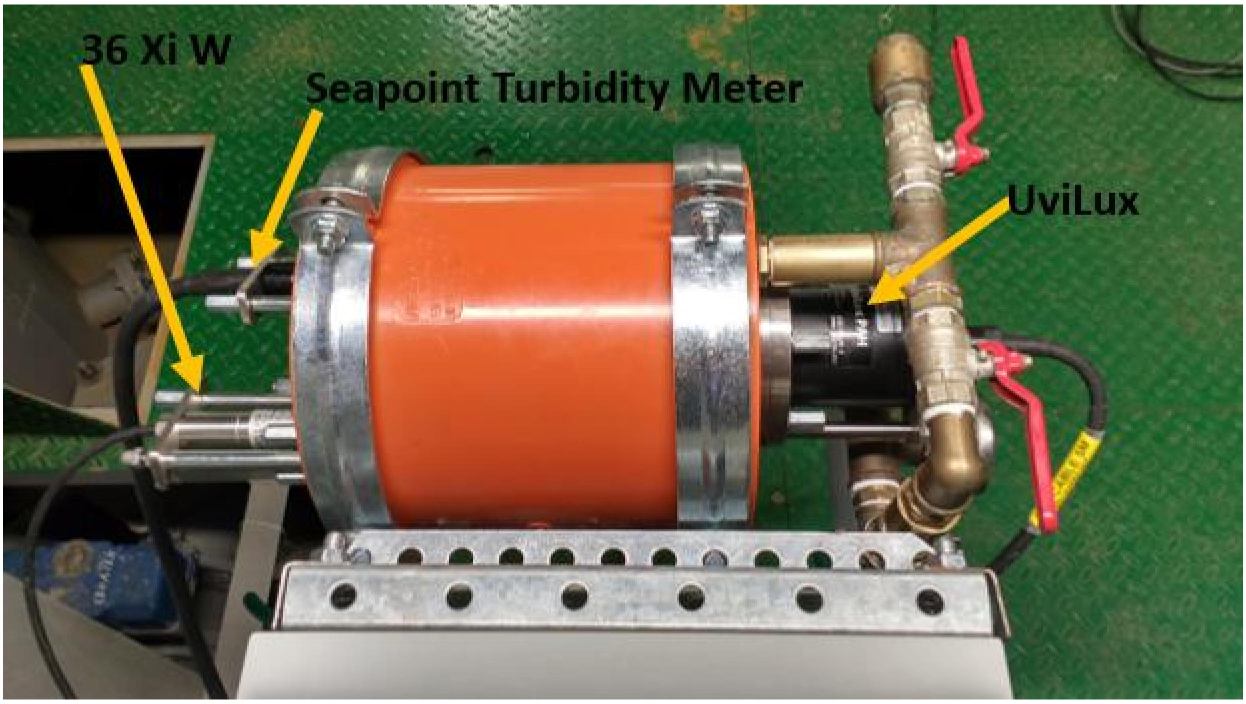
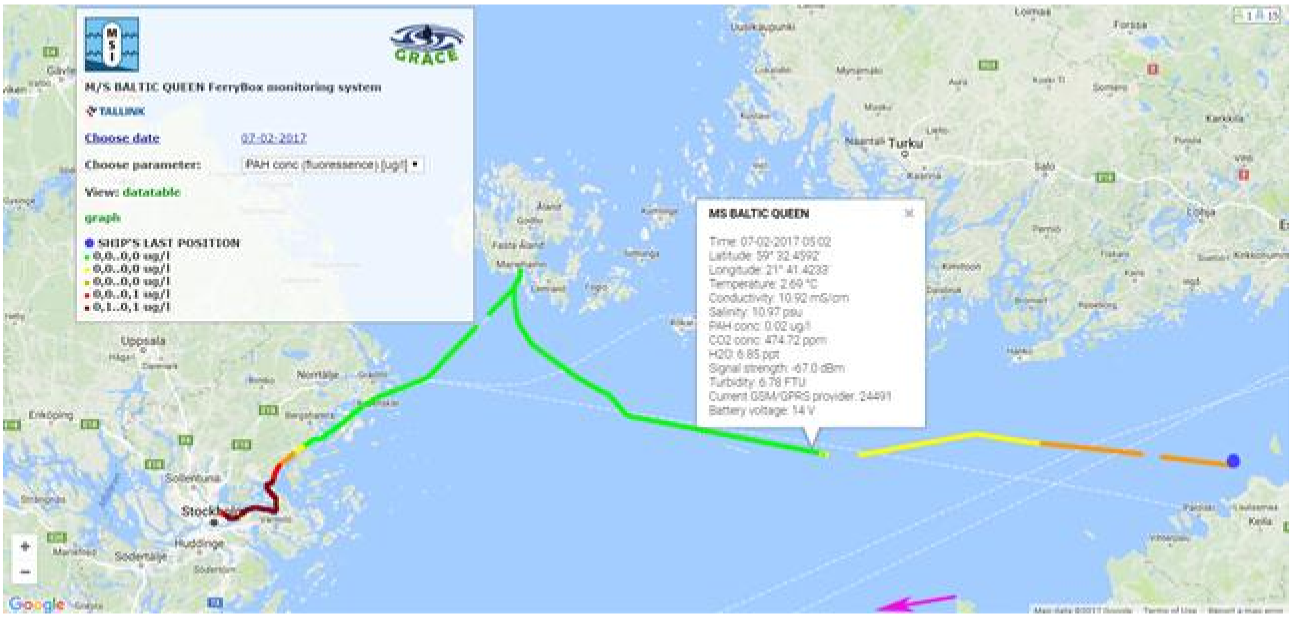


Figure 14 Sensors on FerryBox system aboard M/S BALTIC QUEEN.

2.4 Data transmission and web based user interface

Next step after measurements and data collected by the datalogger is to transfer it in real time into on shore FTP server of the Marine Systems Institute, using GSM/GPRS protocol with one minute interval. For data transmission from ship to shore additional device is required, a GSM/GPRS modem. The modem, that is located on top of the ferry contains a SD memory card, where all the collected data is stored. It also receives data from GPS receiver with antenna. GPS data and time stamps are added to the FerryBox measurement data. The FerryBox system on board records data every minute, data transmission from the ship into on shore FTP server also occurs with one-minute interval, which allows to set up the real time alert systems to all parameters, if needed. Settings of the GSM/GPRS modem were remotely adjustable during operation.

Received data is represented on webpage - http://on-line.msi.ttu.ee/GRACEferry/ , where FerryBox data and ship's track as well current position can be seen both in real time and with historical views. The web based user interface is equipped with different options: user can make selection of parameters, time periods, construct map view and 2D graphs of single and multiple parameters. Data is available in tabulated form and can be assessed regarding the quality (Fig. 15).



GRACEferrybox (close window)

Time (local)	Latitude	Longitude	Temperature [°C]	Conductivity [mS/cm]	Salinity [psu]	O2 Conc [uM]	O2 Air Satur [%]	Chlorophyll-a [ug/l]	Turbidity [FTU]	Phycocyanin [ug/l]	PAH conc [ug/l]	PAH data quality	CO2 con [ppm]	H2O [ppt]	Signal strength [dBm]	Current GSM/GPRS provider	Battery voltage [V]
06.02.2017 17:00	59° 21.0273'	18° 6.7625'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.77	15.21	-51	24001	14.3
06.02.2017 17:01	59° 21.0268'	18° 6.7622'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.76	15.21	-51	24001	14
06.02.2017 17:02	59° 21.0254'	18° 6.7622'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.71	15.21	-51	24001	14.5
06.02.2017 17:03	59° 21.0256'	18° 6.7607'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.53	15.21	-51	24001	15.3
06.02.2017 17:04	59° 21.0261'	18° 6.7622'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.45	15.21	-51	24001	15
06.02.2017 17:05	59° 21.0266'	18° 6.7637'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.4	15.21	-51	24001	14
06.02.2017 17:06	59° 21.0274'	18° 6.7646'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.07	15.21	-51	24001	14.3
06.02.2017 17:07	59° 21.0284'	18° 6.765'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	839.19	15.21	-51	24001	14.3
06.02.2017 17:08	59° 21.0285'	18° 6.765'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.95	15.21	-51	24001	14.2
06.02.2017 17:09	59° 21.0276'	18° 6.7649'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.91	15.21	-51	24001	14.1
06.02.2017 17:10	59° 21.027'	18° 6.7637'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.66	15.21	-51	24001	14.8
06.02.2017 17:11	59° 21.0285'	18° 6.7642'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.67	15.2	-51	24001	14.3
06.02.2017 17:12	59° 21.0287'	18° 6.764'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.49	15.2	-51	24001	14.4
06.02.2017 17:13	59° 21.028'	18° 6.7647'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.42	15.21	-51	24001	14.2
06.02.2017 17:14	59° 21.0283'	18° 6.7633'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.25	15.21	-51	24001	15
06.02.2017 17:15	59° 21.0295'	18° 6.765'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.22	15.2	-51	24001	15.1
06.02.2017 17:16	59° 21.0294'	18° 6.7668'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	838.02	15.2	-51	24001	14.4
06.02.2017 17:17	59° 21.0291'	18° 6.767'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.93	15.2	-51	24001	15
06.02.2017 17:18	59° 21.028'	18° 6.7662'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.81	15.2	-51	24001	15
06.02.2017 17:19	59° 21.0289'	18° 6.7648'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.68	15.21	-51	24001	14.4
06.02.2017 17:20	59° 21.0268'	18° 6.7645'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.42	15.2	-51	24001	14.6
06.02.2017 17:21	59° 21.0267'	18° 6.7646'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.39	15.2	-51	24001	14.5
06.02.2017 17:22	59° 21.0261'	18° 6.766'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.32	15.2	-51	24001	14
06.02.2017 17:23	59° 21.0275'	18° 6.7657'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.17	15.2	-51	24001	15
06.02.2017 17:24	59° 21.0283'	18° 6.7662'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	837.18	15.2	-51	24001	14.5
06.02.2017 17:25	59° 21.0295'	18° 6.7671'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	836.93	15.2	-51	24001	15
06.02.2017 17:26	59° 21.0285'	18° 6.7654'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	836.92	15.2	-51	24001	14.4
06.02.2017 17:27	59° 21.0275'	18° 6.7645'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	836.74	15.21	-51	24001	14.5
06.02.2017 17:28	59° 21.0274'	18° 6.7653'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	836.61	15.2	-51	24001	14.2
06.02.2017 17:29	59° 21.0277'	18° 6.7663'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	836.58	15.2	-51	24001	14.8
06.02.2017 17:30	59° 21.0289'	18° 6.766'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	836.48	15.21	-51	24001	14.6
06.02.2017 17:31	59° 21.0287'	18° 6.7649'	51.17	0.0	0.01	0.0	0.0	0.0	0.0	0.0	-0.08	0.0	836.35	15.21	-51	24001	15.2

Figure 15 On-line system http://on-line.msi.ttu.ee/GRACEferry that enables opportunity for real-time observation, both, environmental parameters and system's condition. Different parameter values are visualized operationally color-coded (upper panel); additional option is display data table.

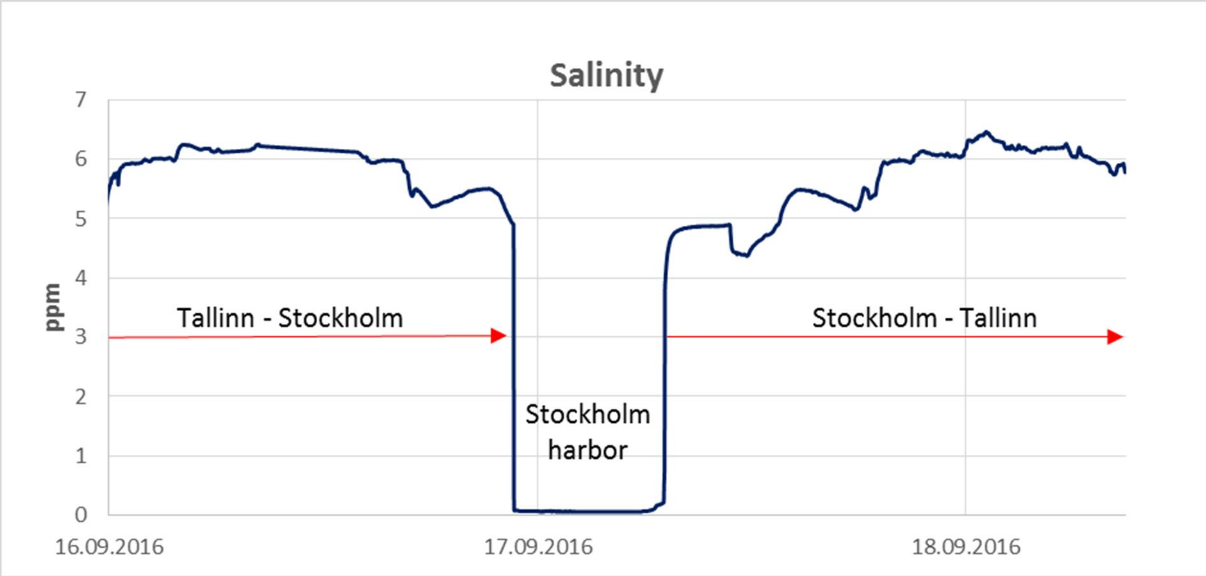


Figure 16 Example of salinity measurements on Tallinn-Stockholm-Tallinn trip. In harbours FerryBox chamber was emptied in order to avoid fouling of the sensors

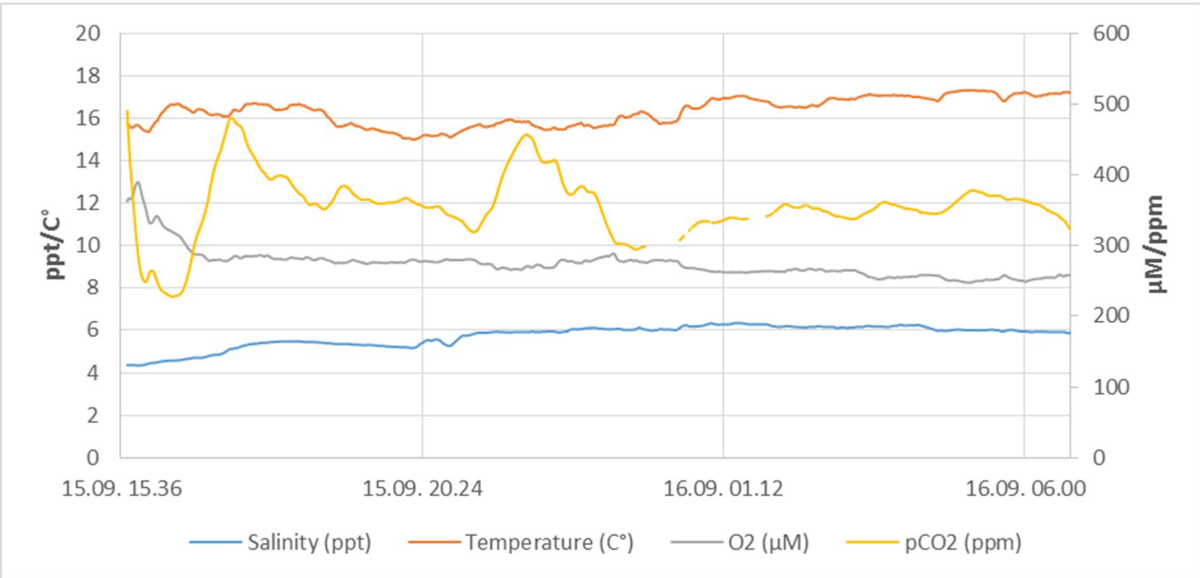


Figure 17 Example of parameters measured in September 15-16, 2016 on Tallinn-Stockholm trip - salinity, temperature and O_2 and pCO_2 concentration were measured.

2.5 Maintenance and service of FerryBox system

In order to collect reliable high quality data, every device requires regular maintenance. This can be done automatically or manually. FerryBox system on board of M/S ROMANTIKA required direct visits and actions by an operator. It is important to understand, that it is inevitable and most important part, when operating the system. Otherwise, collected data is poor quality. Maintenance means cleaning of the sensors. The need for that comes from the fact, that huge amount of water passing through the FerryBox tubes and chamber, contains more or less suspension, which accumulates on the sensors (Fig. 18). There is also biological aspect: there are different algae/bacteria in seawater, which form a biofilm on the sensors, inner surface of tubes and walls of the measurement chamber. The result is declined and poor data quality. The aforementioned reasons force to visit FerryBox regularly, frequency of which depends on season and particularly water temperature – once a week in summer or once a month in winter. Standards for data quality agreed before data compilation should not be forgotten.

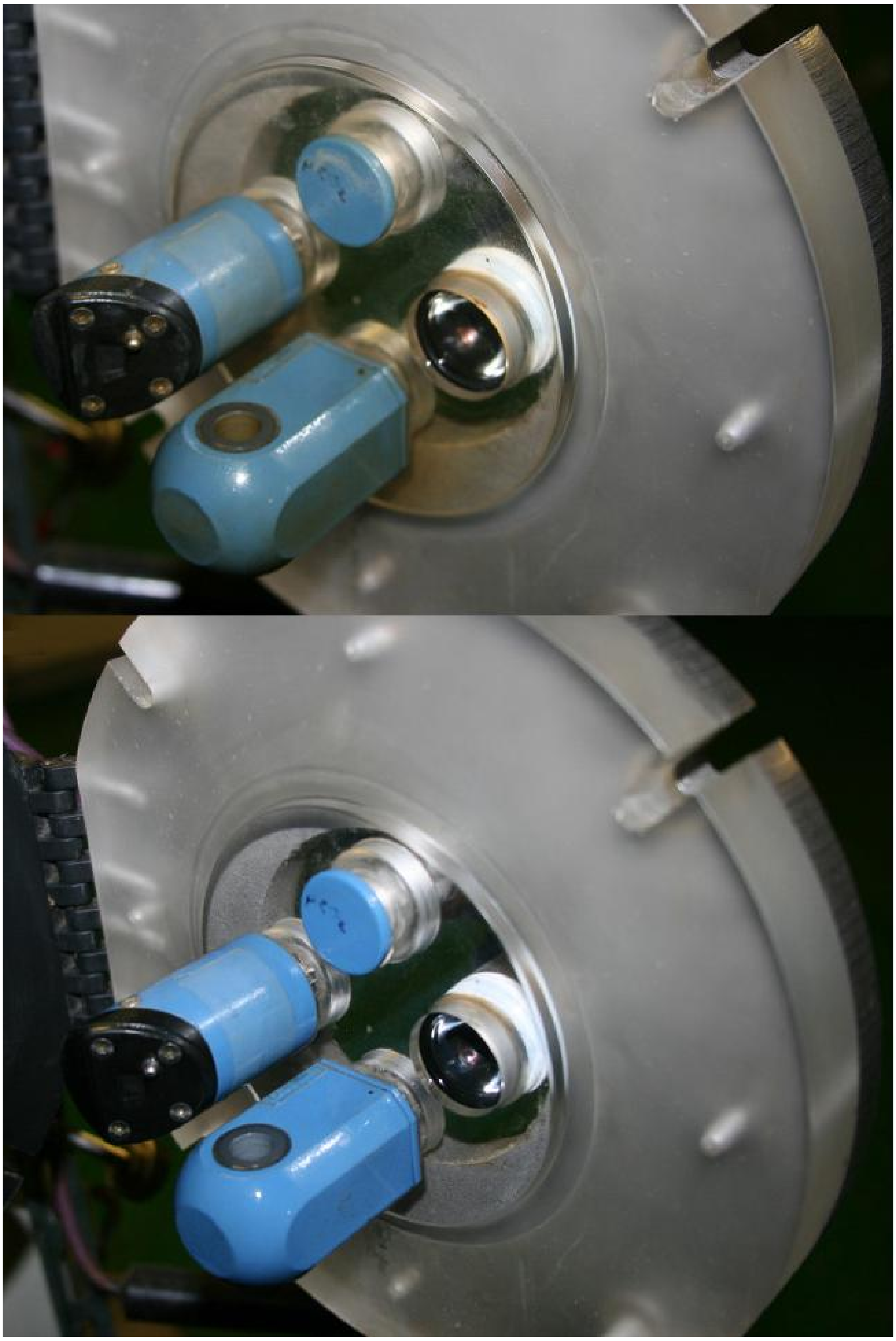


Figure 18 FerryBox sensors on board M/S ROMANTIKA before and after cleaning [22]

From technical perspective view, namely backup, the data from SD memory card should also be downloaded. The reason for that are gaps in data series transferred into server caused by absence of GSM coverage at open sea, far from coasts, therefore breaks in on-line datastream. When the distance between ship and GSM base station is too long or environmental conditions have negative effect to radio signal propagation. On top of that, timers, which control functioning the water pump and solenoid valves, must be checked and if necessary, their clocks synchronized.

2.6 Testing the UviLux UV fluorometer on board M/S ROMANTIKA

During the BONUS project GEOILWATCH, first tests with UviLux UV fluorometer (Fig.19) were performed on board M/S ROMANTIKA. Sensor was installed with its own flow chamber (Fig. 19) to the water stream of the FerryBox system for testing. Additional parameters recorded in same time with UviLux fluorometer were water temperature, salinity, turbidity, chlorophyll-a, phycocyanin, O_2 and pCO_2 concentrations. Tests with UviLux sensor showed maximum values of PAH concentration up to 2.6 µg/L on Tallinn-Stockholm fairway and remarkable variability along the ship track. During the testing problems rose with data quality, most probably due to biofouling and further developments of the system was needed (Fig. 20). [22]

Figure 19 UviLux Fluorometer by Chelsey Technology Group   Image credit: Chelsey Technology Group

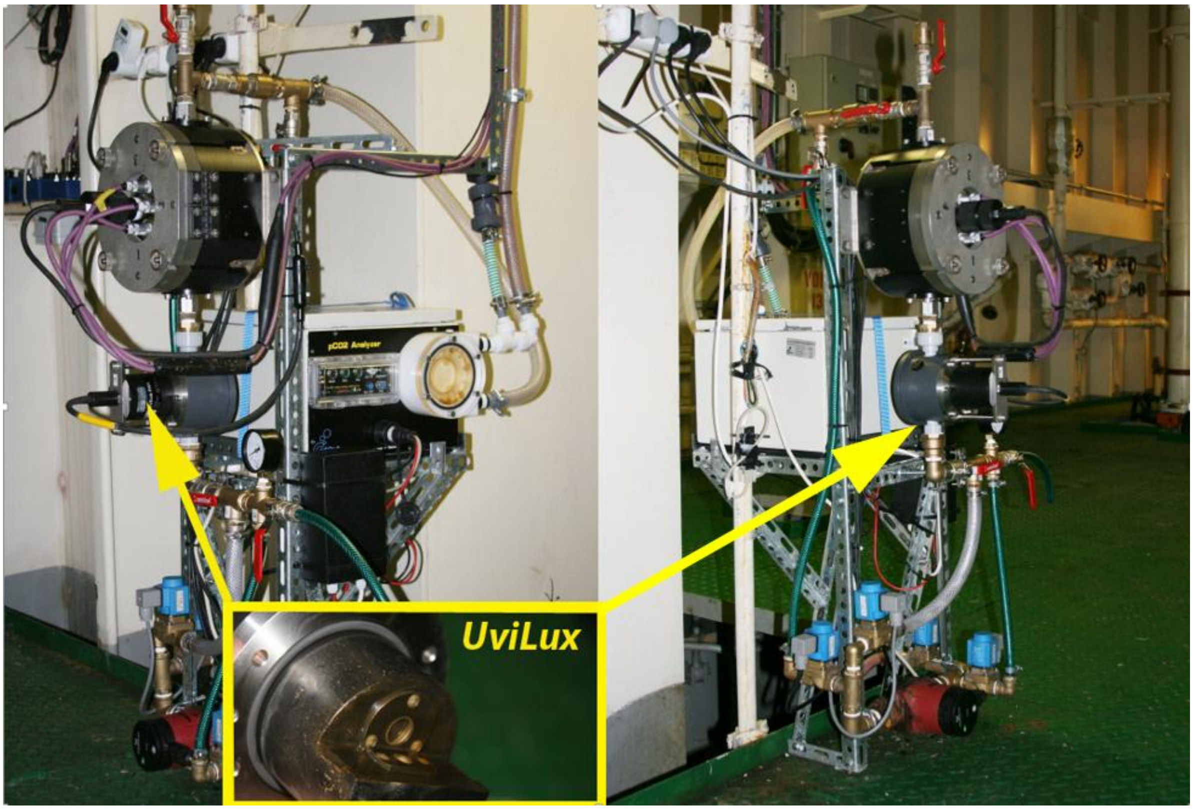


Figure 20 UviLux Fluorometer in flow chamber, installed to the FerryBox system [22]

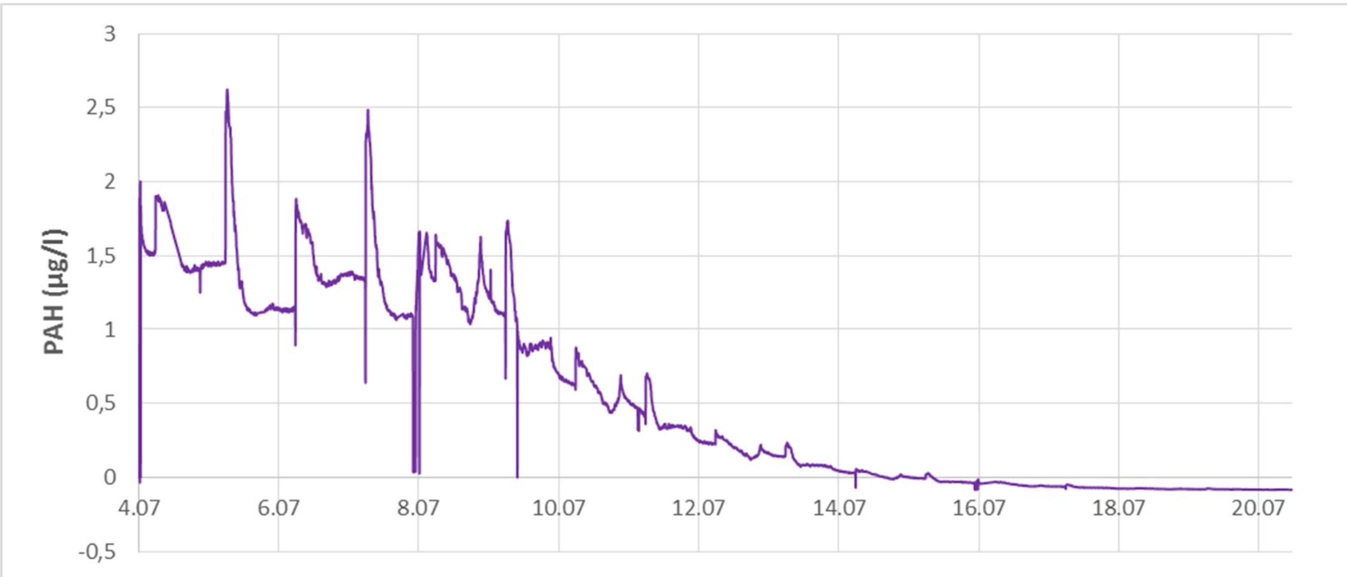


Figure 21 PAH (µg/l) readings by UviLux fluorometer. Decline of sensor sensitivity during two weeks period can be well seen. [22]

2.7 Oil detection functionality of FerryBox system on M/S BALTIC QUEEN

For oil detection functionality the UviLux fluorometer (Fig. 19) from Chelsey Technology Group (UK) was added to the FerryBox system (Fig. 20). As there were problems with fouling in previous test, this time the sensor was installed to the larger main chamber (Fig. 14) not separately with its own flow-chamber (Fig. 19). The oil detection is done by proxy of Polycyclic Aromatic Hydrocarbon (PAH) concentration (in terms of Carbazole) with unit µg/L. Data transmission and representation and web based user interface are the same as described in previous sections. Data is in real time shown on a webpage http://on-line.msi.ttu.ee/GRACEferry/. Real time alert systems can also be set up, to notify when concentrations rise over certain levels.

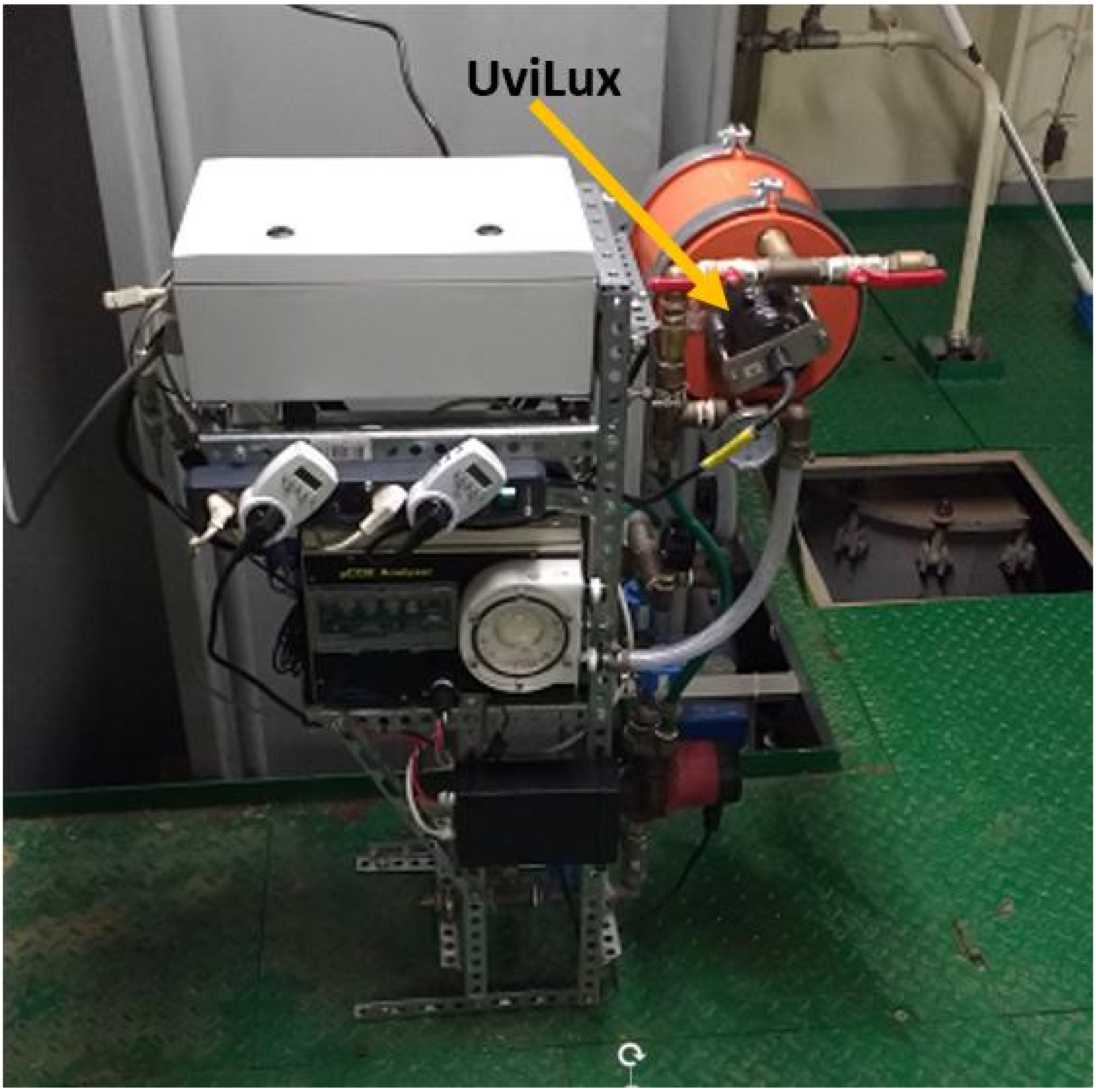


Figure 22 UviLux Fluorometer on FerryBox system on M/S BALTIC QUEEN

2.8 First results of oil compound monitoring on Tallinn-Stockholm fairway with FerryBox system on board M/S BALTIC QUEEN

Preliminary results of PAH measurements with FerryBox system on M/S BALTIC QUEEN during the period 5.-14. February 2017, showed good data quality. Figures 23 and 24 show similar pattern of variability along the track, it does not matter which direction ship proceeded and differences in concentration of oil compounds can be seen between coastal areas and the open sea. In all, PAH concentration were quite consistent when different trips were compared and varied between 0.014 µg/l and 0.093 µg/l. Sea surface temperatures between Tallinn and Stockholm shown on Fig 25 and 26 stayed between 0.3-3 °C, which shows mild winter conditions in the Baltic Sea. Ice was only present in the Stockholm archipelago, so we can say that at least some of measurements done in icy conditions. Data transmission worked fine but some interruptions in the connection occur. Fresh on-line data and archived data are available in http://on-line.msi.ttu.ee/GRACEferry.

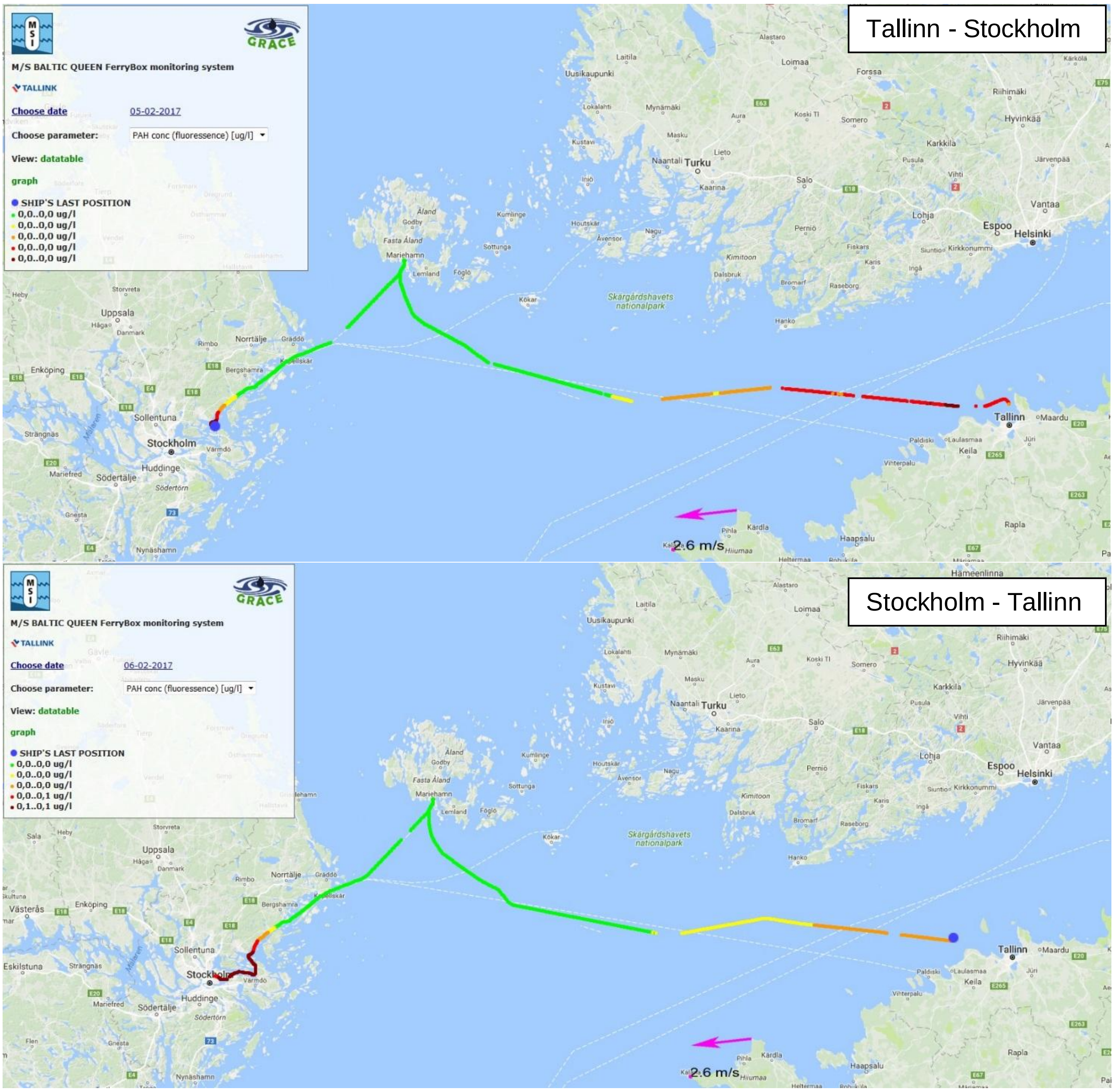


Figure 23 Color-coded trajectory of PAH measurements on Tallinn-Stockholm (5.02.2017-6.2.2017 and Stockholm-Tallinn (6.02.2017-7.02.2017) route, as presented in web-based user interface http://on-line.msi.ttu.ee/GRACEferry .

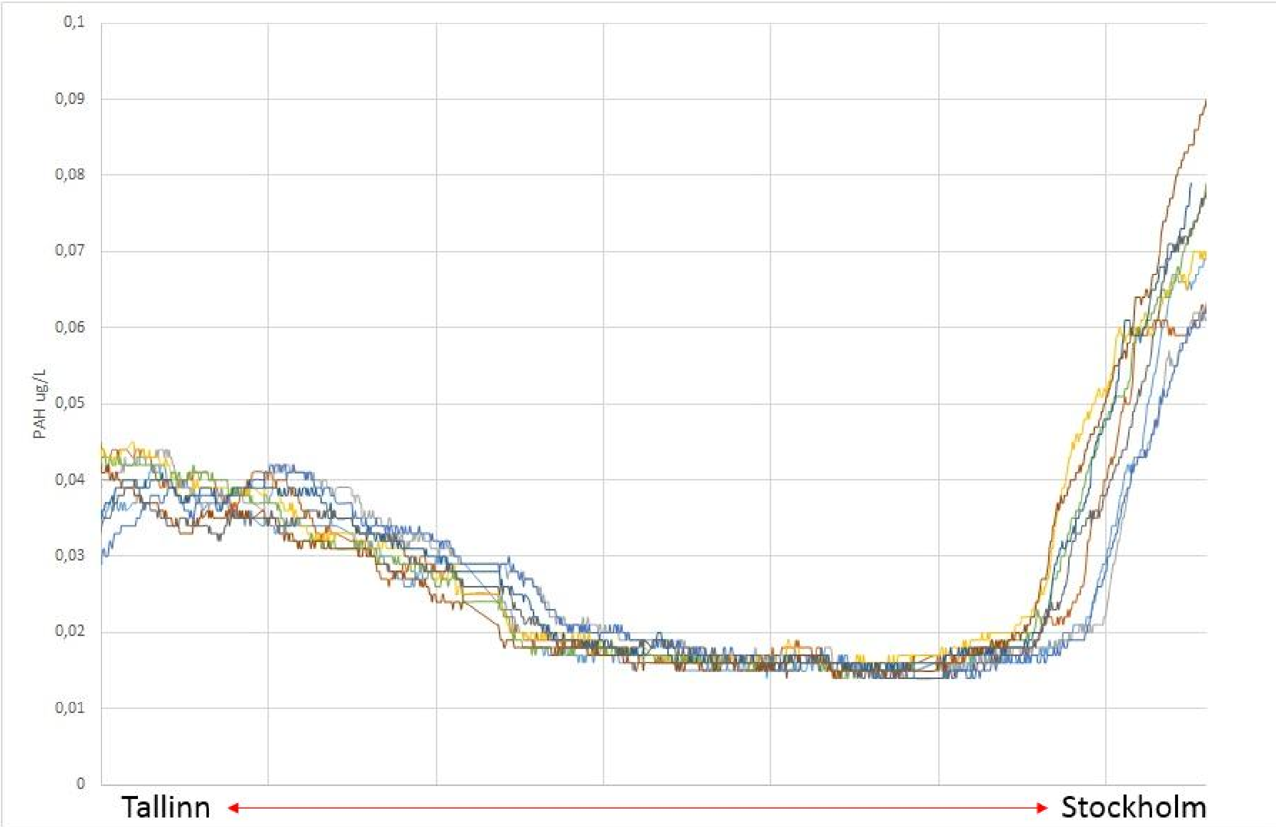


Figure 24 Oil compounds PAH measurement results on Tallinn-Stockholm and Stockholm-Tallinn routes during 9 trips (5.02.2017-14.02.2017).

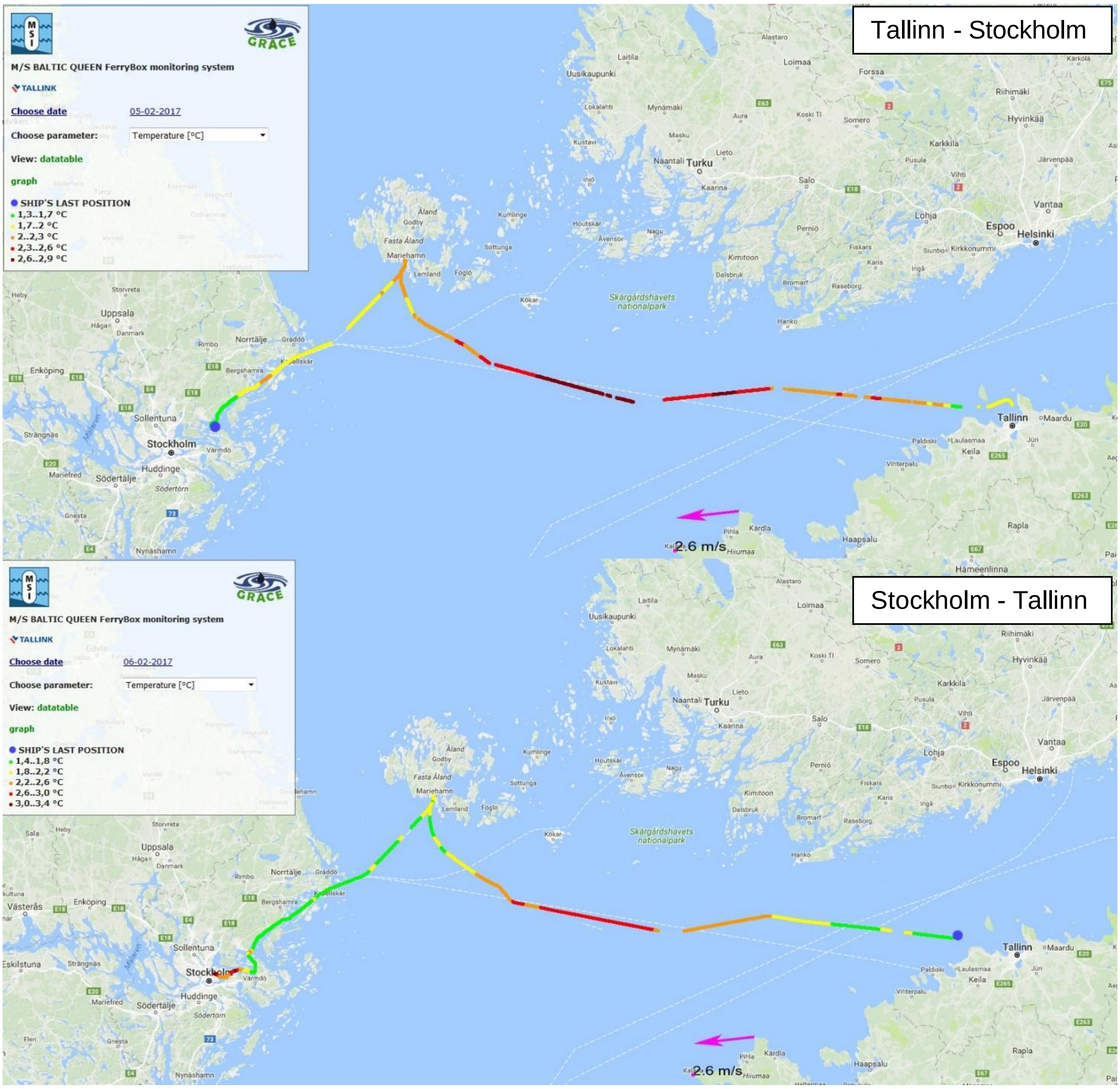


Figure 25 Color-coded trajectory of temperature measurements on Tallinn-Stockholm (5.02.2017-6.02.2017 and Stockholm-Tallinn (6.02.2017-7.2.2017) route, as presented in web-based user interface http://on-line.msi.ttu.ee/GRACEferry .

Figure 26 Seawater temperature as measured along ship track on Tallinn-Stockholm and Stockholm-Tallinn routes during 9 trips (5.02.2017-14.02.2017).

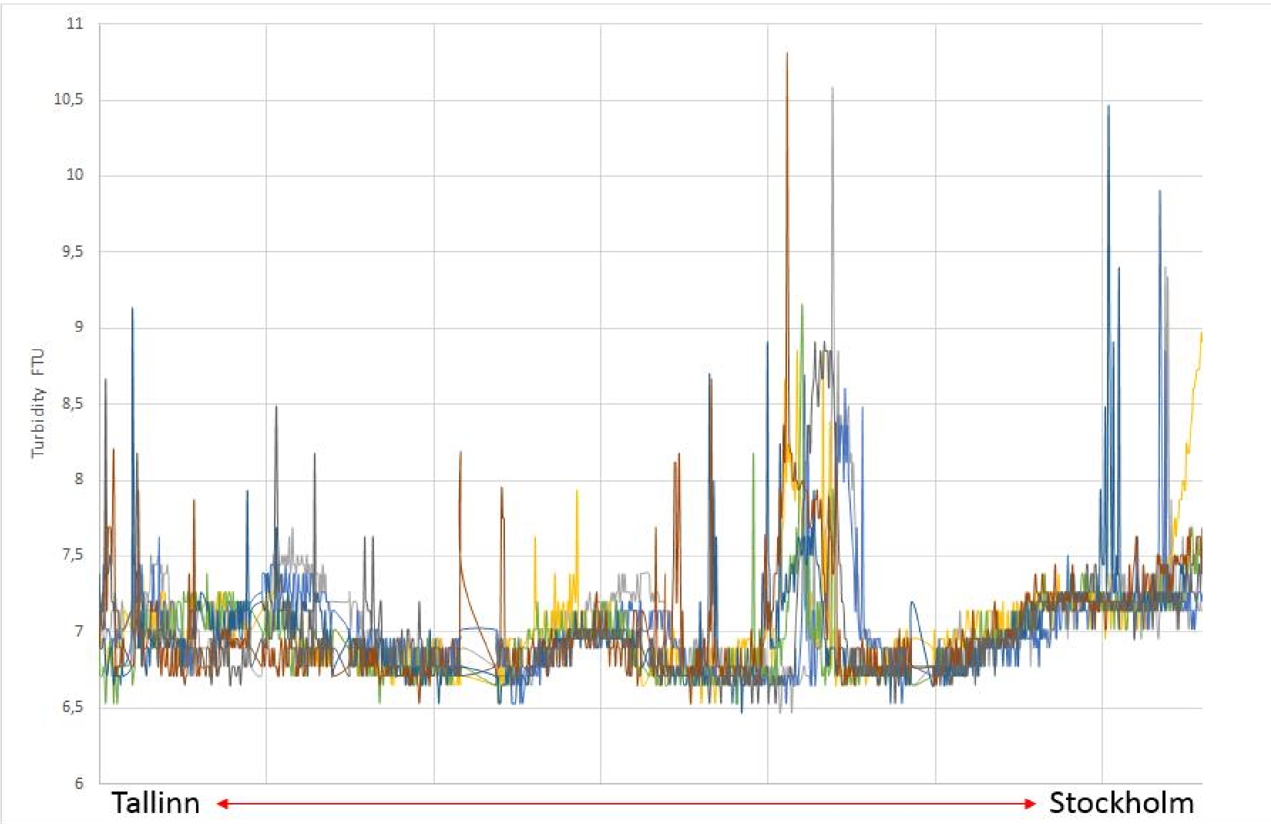


Figure 27 Seawater turbidity as measured along ship track on Tallinn-Stockholm and Stockholm-Tallinn routes during 7 trips (10.02.2017-14.02.2017). Higher peaks in the middle of the graph are ship entrance into the Mariehamn harbor in Åland, probably resuspended sediments in the harbour.

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