Ocean observing systems: review of practical approaches and experiences

Scientific note from DCE – Danish Centre for Environment and Energy & Havsans

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Data sheet

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Front page photo:	Photo showing sensor retrieved from coastal waters (150 m depth) of the Great Barrier Reef, Australia after one year of deployment (photo taken by C. Lønborg)
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1 Preface

This briefing is completed by Aarhus University (AU) and Havsans. The main purpose of this briefing is to provide a short overview of practical experience and knowledge gained from ocean observation systems in Denmark and other countries. This briefing is a delivery under the Integrated Environmental Monitoring project financed by the Danish Environmental Protection Agency through a grant to DTU Aqua.

The focus of this briefing is on the practical approaches used and recommendation on the use and practical considerations that should be made before purchasing a sensor setup.

2 Introduction

Danish coastal waters are dynamic system which are spatially different and experience rapid temporal changes in the physical, chemical and biological environment (Conley et al., 2000). Many coastal systems, Fjords in particular, are often characterized by gradients in salinity, concentration of nutrients, chlorophyll and clear differences in the distribution of vegetation and benthic fauna. These characteristics makes them not only expensive but also difficult to monitor at a high enough resolution. Due to this these coastal systems are often under sampled of biogeochemical variables through routine biweekly to monthly sampling (Stæhr et al., 2021). It is therefore important to monitor the environmental conditions effectively to get a better understanding of the importance of coastal waters and their contribution to achieving a good environmental condition in the open sea (Carstensen et al., 2020). A good understanding of the natural and man-made conditions that affect the state of the environment is a prerequisite for obtaining the goals of both the European Water Framework Directive and the Marine Strategy Framework Directive.

While autonomous sensors have been successfully used in physical oceanography (e.g., salinity and temperature sensors), methods to obtain standardized biogeochemical observations at similar resolutions are less developed. Sensor-based technologies suitable for autonomous platforms (e.g., buoys) are now however beginning to be commercially available and they have the potential to provide data at high resolution. Nonetheless, the usefulness of these sensors depends strongly on whether the obtained data are consistent with historical data and standard laboratory methods. Currently agreed best practices for these techniques are often lacking, which limits the use of these techniques in routine monitoring programs. Therefore, there is a need to validate new sensor technologies by conducting inter-comparisons and standardization of measurements.

In the European Union (EU) alone around €1.5 billion annual is spent on ocean observations by EU Member States (European Union, 2022). These investments show that on a European scale large efforts are being made to collect sensor-derived data. In a Danish context especially the multiple regional operational systems within the Northwest Shelf (NOOS; https://noos.eurogoos.eu/) and Baltic Operational Oceanographic system (BOOS; https://eurogoos.eu/roos/baltic-operational-oceanographic-system-boos/) which are coordinated under the European Global Ocean Observing System (EUROGOOS) are of interest.

In this brief document, we: 1) provide an overview of some of the existing and previous deployed observing platforms in both Danish coastal waters and internationally and 2) summarize experience and knowledge gained from some of these observation systems.

3 Parameters available from buoy systems

Buoy systems can be equipped with a range of sensors providing high frequency information on conditions in the water column as well as local meteorological conditions affecting water column properties. Some of the different parameters, their use and relation to environmental drivers are summarized in **Table 1**.

Table 1. Typical sensors on marine measurement buoys, their measurement units, application and relevant environmental drivers of change.

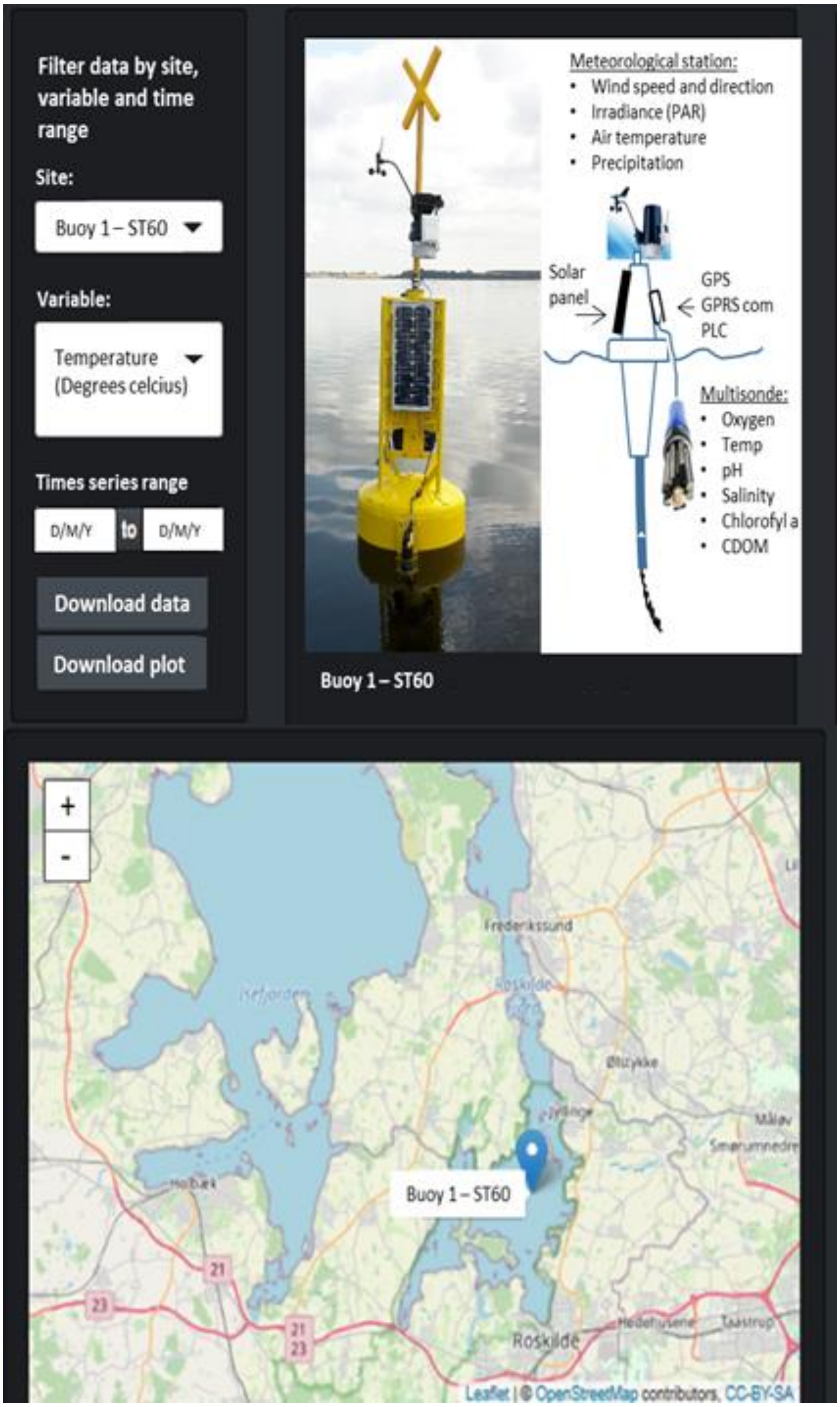
Where	Parameter	Unit	Use	Driver
Water column	Temperature	ºC	Stratification (multiple depths) Heat waves	Climate
	Salinity	psu	Trace water masses, stratification (multiple depths)	Climate
	Oxygen	mg O_2 / L and %saturation	Primary production, respiration, oxygen depletion	Eutrophication
	pH	-	Inorganic C	Climate (acidification)
	CO_2	µg CO_2 / L and %saturation	Primary production, respiration, inorganic C	Eutrophication Climate (acidification)
	Chlorophyll a	(µg / L)	Algal blooms, Primary production	Eutrophication
	Phycocyanin	(µg / L)	Blue green algae	Eutrophication
	Turbidity	(FNU)	Water clarity	Eutrophication
	Total suspended material	(mg / L)	Water clarity, particles	Eutrophication
	FDOM	(RFU)	Colored dissolved organic material	Eutrophication
	Nitrate	(µg / L)	Nitrate concentrations	Eutrophication
Air	Irradiance (PAR)	µmol fotons/ m^2/ s or W / s	Calculate primary production	Weather, storm, climate
	Wind speed	m / s	Calculate gas exchange, Model stratification	
	Wind direction	degrees	Trace water masses	
	Relative humidity	%	Shifts in weather	
	Temperature	ºC	Heatwaves	
	Atmospheric pressure	mBar	Shifts in weather	

4 Ocean observing systems in Danish Waters

Below we will provide a brief overview of existing and previous deployed observing platforms in Danish coastal waters. This will focus on the approaches used as well as some of the outcomes gained from these observation systems.

Buoy in Roskilde Fjord – Since 2012, the national marine monitoring of the inner part of Roskilde Fjord, has been supplemented with an automated buoy system. The system has been equipped a range of water quality sensors, including stand alone and multi sensor systems. In 2016 the buoy was upgraded to an online system equipped with a meteorological station (**Figure 1**) as part of a project (SEASTATUS) funded by Innovation fund Denmark.

Figure 1. Monitoring buoy in the southern part of Roskilde Fjord at NOVANA station 60. Data is transmitted via the mobile network to a server and can be accessed online. The buoy was developed in collaboration with the Danish Maritime Authorities and Electromec.dk.



The buoy in Roskilde Fjord has supplemented the discrete water quality sampling with high frequency data enabling detailed understanding of the importance of weather events for changes in water quality parameters and processes associated with productivity of the system (Stæhr et al., 2021) (**Figure 2**).

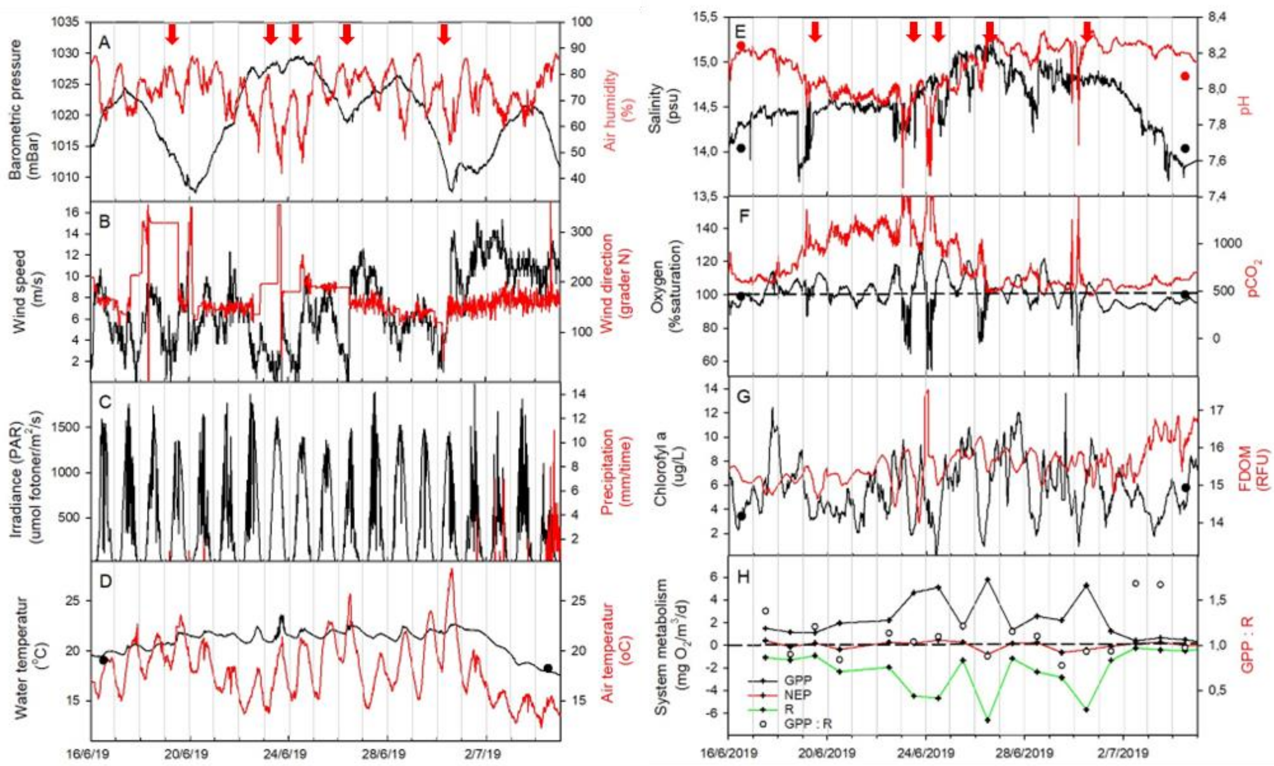


Figure 2. Data collected during a three-week period in 2019 from a buoy in Roskilde Fjord. Left panel shows meteorological data, right panel a range of water quality parameters and processes representing gross primary productivity (GPP), respiration (R) and net ecosystem productivity (NEP). Red arrows indicate meteorological events which triggered changes in water column physical, chemical, and biological conditions affecting the productivity of the system. Black dots indicate timing of NOVANA sampling.

The close and sensitive interaction between regulatory conditions and environmental conditions in Roskilde Fjord, shows the strength of following the fjord system with high-frequency measurements. For comparison, in the three-week period shown above, there were only two ship-based measurements (black dots). The low frequency offered by ship-based measurements cannot capture the short-term dynamics seen due to the diurnal variation in turnover and short-term weather events. In contrast, the ship measurements can provide a good understanding of the overall seasonal and year-to-year dynamics, while the high-frequency measurements can provide a greater understanding of the significance of short-term but potentially very important events (Staehr et al., 2018).

Oxygen monitoring in Southern Funen - In collaboration with the Danish Environmental Protection Agency, Havsans carried out two monitoring campaigns to measure dissolved oxygen concentrations at fixed locations in the inner Danish Waters south of Funen. The first campaign was conducted in the summer of 2021 as part of a development and demonstration project initiated by Havsans. The second campaign which was carried out summer 2022 was part of an earlier stage of a project in which Havsans acted as a consultant for DHI.

Both monitoring campaigns consisted of measuring salinity, temperature and dissolved oxygen, using sensors mounted in fixed positions close to the seabed. The instrumentation consisted of a data recorder designed and built by Havsans which recorded data from a dissolved oxygen sensor (Insite IG) and a conductivity sensor (Atlas Scientific). Data recorders and sensors were mounted on a lander-type rig placed on the bottom (**Figure 3**). The data recorder was connected to a telemetry module which was mounted on the marker buoy. Raw sensor data were stored locally and time-averaged data were transmitted to a server every 30 minutes to provide real-time data on Havsans' data portal.

Figure 3. Equipment used in the Havsans oxygen monitoring campaigns. Left: Bottom rigs holding the datalogger and batteries. Sensors are mounted on the leg to the right. Right: Marker buoy fitted with telemetry module

The number and locations of measurement stations varied between the two campaigns. The below **Figure 4** shows the deployment locations included in the 2022 campaign.

Figure 4. Satellite image showing the locations of the 4 locations where measurements were carried out as part of the 2022 Havsans oxygen measurement campaign. Helnæs, Helnæs Bugt and Ærø stations correspond to NOVANA monitoring locations (numbers refer to NOVANA stations) whereas the Ballen station is located approximately 1.8 km from the corresponding NOVANA station.

The 2022 campaign produced time series of salinity, temperature and dissolved oxygen with a duration of just under three months from four different locations (**Figure 5**). The collected data was compared to profile data from NOVANA showing good agreement between the two data sets. As illustrated by the data shown in **Figure 5**, the high temporal resolution of the Havsans data makes it possible to observe short-term variations in the measured values, especially dissolved oxygen concentrations.

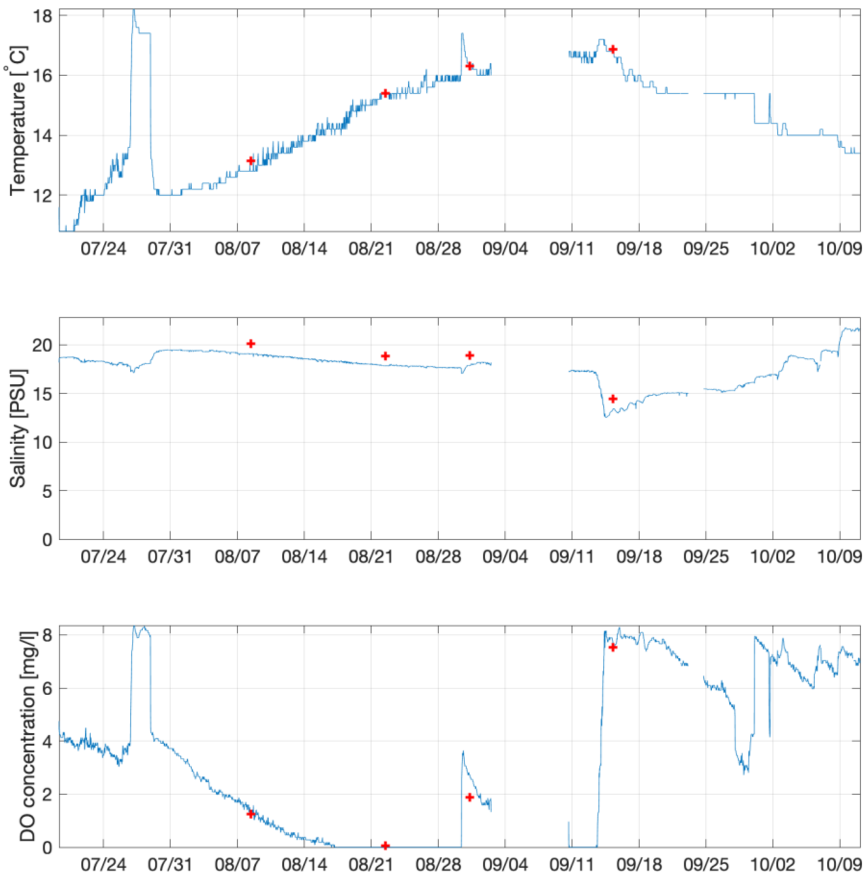


Figure 5. Example of data collected during the Havsans measurement campaigns. Shown data is from the 2022 measurements at the Ballen station. Red markers show data from profile measurements at the nearby NOVANA station.

Monitoring for the Fehmarnbelt Fixed Link project - Extensive environmental monitoring is being carried out to document potential impacts of the Fehmarnbelt Fixed Link project. As part of this monitoring, the FEMO consortium (Bio consult, MariLim, Orbicon and DHI A/S) has been measuring a large number of hydrographic and water quality parameters in the central part of Fehmarnbelt and in Rødsand lagoon (**Figure 6**).

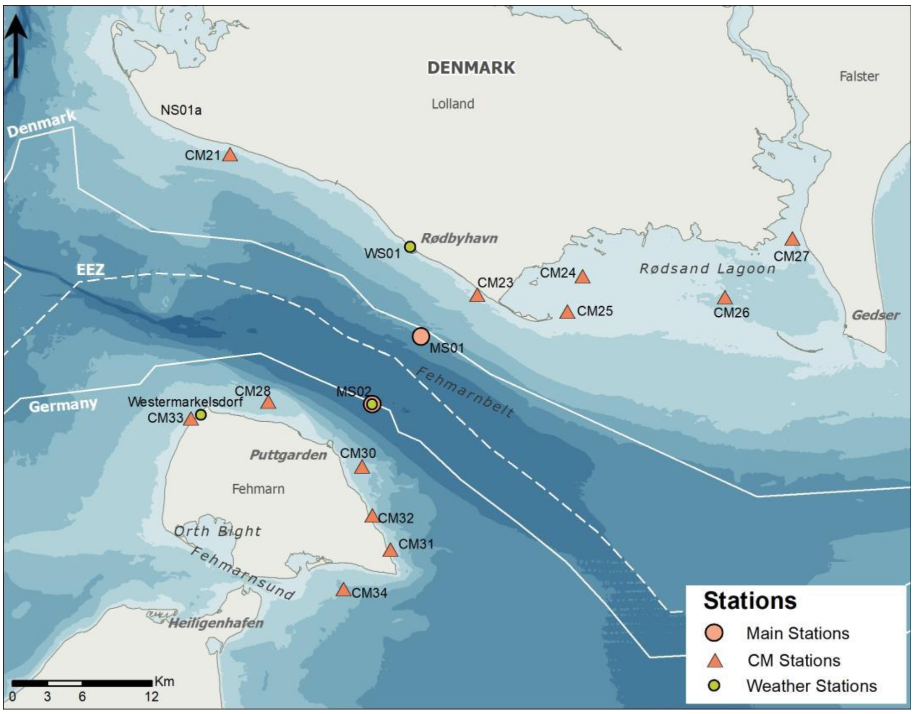


Figure 6. Locations of measurement stations included in the marine monitoring for the Fehmarnbelt Fixed Link project.

The monitoring program for hydrography and water quality thus includes two main stations (MS) and 12 coastal monitoring (CM) stations. The details for all stations are listed in **Table 2**. Except for occasional periods of downtime, all stations have been operating year-round since 2018.

Table 2. Details of the monitoring stations included in the environmental monitoring for the Fehmarnbelt Fixed Link project.

ID	Lat (deg)	Lon (deg)	Bed level (m) DRV90	Parameters collected
MS01	54.5855	11.3558	-19.9	Current profile (speed and direction) with data every 0.75 m Wave parameters Salinity every 2 m Temperature every 2 m Turbidity bottom/mid/top Chlorophyll-*a* fluorescence bottom/mid/top Dissolved Oxygen bottom/mid/top
MS02	54.5340	11.2880	-28.6	Wind speed and direction approx. 3 m above the surface Air temperature Atmospheric pressure Current profile (speed and direction) with data every 0.75 m Wave parameters Salinity every 2 m Temperature every 2m Turbidity bottom/mid/top Chlorophyll-*a* fluorescence bottom/mid/top Dissolved Oxygen bottom/mid/top
CM21	54.7312	11.1089	-6.4	Turbidity
CM23	54.6166	11.4327	-4.8	Turbidity
CM24	54.6279	11.5743	-2.3	Turbidity
CM25	54.6063	11.5597	-1.3	Turbidity
CM26	54.6073	11.7625	-7.3	Turbidity
CM27	54.6508	11.8560	-3.9	Turbidity Current speed and -direction
CM28	54.5388	11.1503	-8.2	Turbidity Current speed and -direction
CM30	54.4864	11.2718	-8.7	Turbidity
CM31	54.4214	11.3061	-5.5	Turbidity
CM32	54.4481	11.2837	-6.0	Turbidity Current speed and -direction
CM33	54.5299	11.0472	-5.1	Turbidity Current speed and -direction
CM34	54.3920	11.2420	-11.4	Turbidity Current speed and -direction

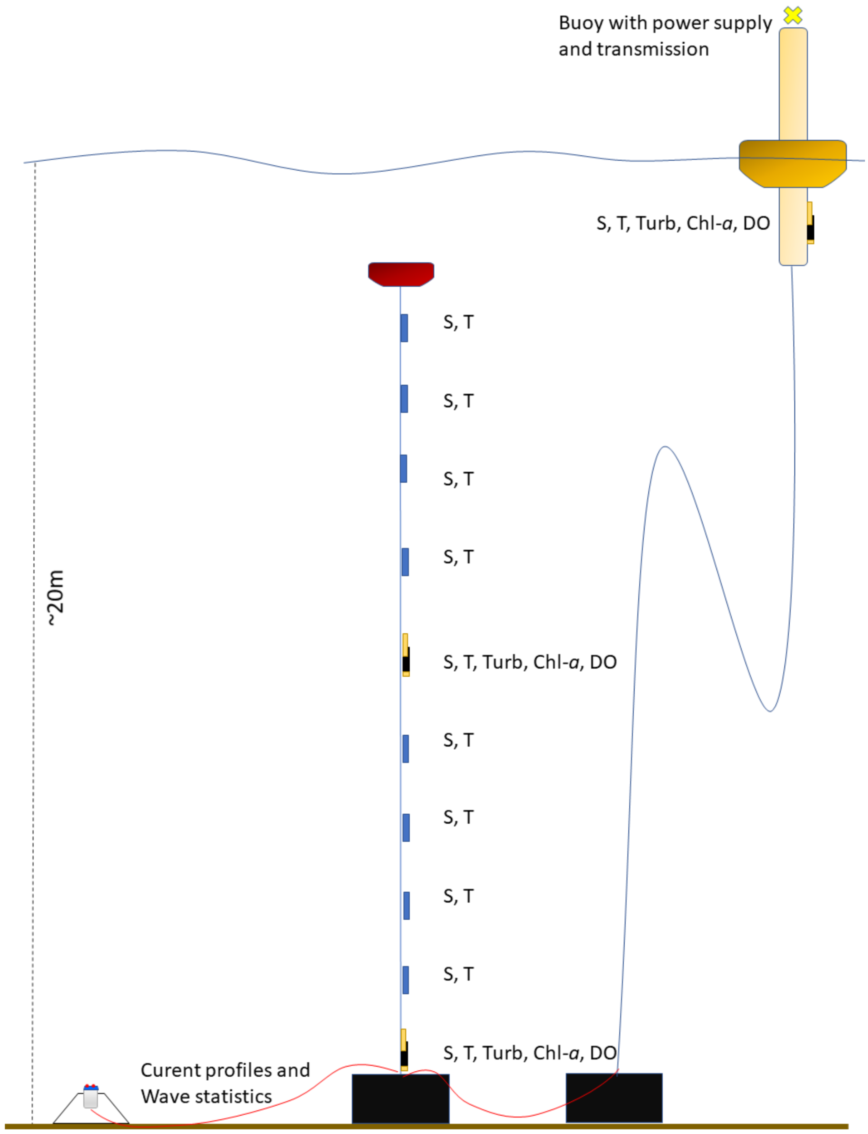
The layout of the main stations is shown in **Figure 7**. The stations monitor the following parameters:

- Current profile with current speed and direction every 0.75 m (using bottom mounted acoustic doppler profiler)
- Wave parameters (using bottom mounted acoustic doppler profiler)
- Salinity and temperature every 2 m of the water column (using SeaBird SBE 37 MicroCAT)

- Environmental parameters: dissolved oxygen, fluorescence and turbidity. Measured near the bed, at mid-water, and near the surface.

All data recorded by instruments at the main stations are stored in the internal instrument memory as well as forwarded to a land-based database. Data is collected from all sensors every 10 minutes (waves every hour). Every hour all collected data is transmitted online to the Data Handling Centre at DHI.

Figure 7. Sketch of the layout of the main stations in the Fehmarn Belt monitoring program. The number of S-T sensor differs between the two stations due to difference in water depth.



The 12 Coastal monitoring stations, six along the coast of Fehmarn and six along the coast of Lolland, monitor turbidity and on some of the stations, also currents (**Table 2**). The layout of the Coastal monitoring stations is shown in **Figure 8**. The coastal stations do not store data internally, but every hour all collected data is transmitted online to the Data Handling Centre at DHI.

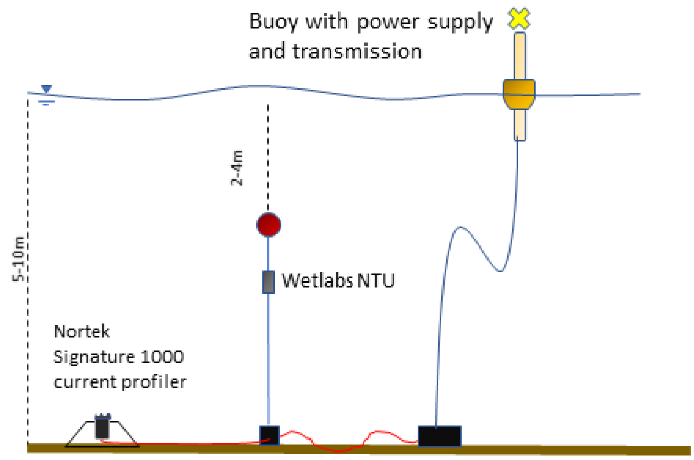


Figure 8. Sketch of the layout of the coastal monitoring stations in the Fehmarnbelt monitoring program. Note that not all stations are equipped with current profilers.

Both data transmitted from the main and coastal stations are imported to a dedicated database. Shortly after, the data can be viewed through a web interface. When data are received, they are automatically processed and validated both. Additionally, the data is manually quality assured. Most of the collected data is made publicly available through the Femern A/S' environmental data portal ÆGIR (**Figure 9**).

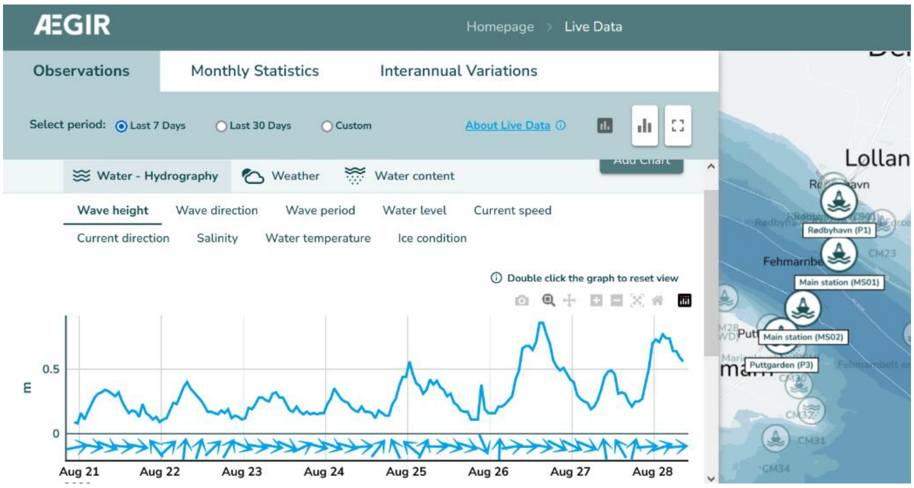
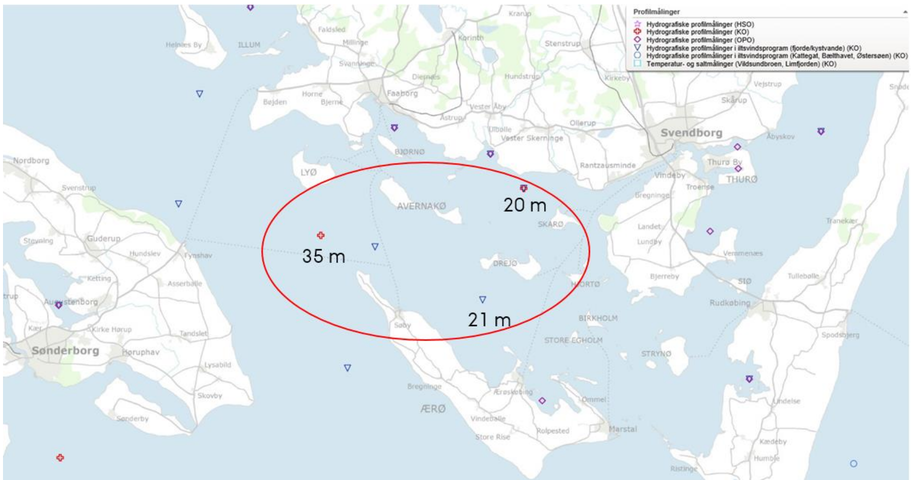


Figure 9. Screenshot from the ÆGIR data portal showing example (wave) data from the Fehmarn Belt monitoring.

Velux oxygen depletion project – As part of the Velux foundation funded project: *Iltsvind – en joker i forvaltningen af det danske havmiljø* (In Danish) (Hansen et al., 2021) three oxygen sensors were deployed in South Funen Archipelago (**Figure 10**). These sensors were deployed at three stations for a period of 9 weeks to follow short-term changes in oxygen levels and oxygen depletion. In order to put the oxygen results into perspectives a temperature and salinity sensor were co-deployed. The results obtained demonstrated how rapid transport of oxic water from nearby oxic areas could shrink the extent of oxygen depletion in heavily affected areas.

Figure 10. Locations of measurement stations included in the Oxygen monitoring project financed by the Velux Foundation.



Ferry Box system – The use of Ferry box systems with associated sensors in Danish waters was reviewed as part of the Danish EPA funded project: *Monitoring of open Danish marine waters with FerryBox systems: Examples from the North Sea and Inner Danish Waters* (Murray et al., 2022). The project focused on the use of Ferry box systems for the monitoring under the Marine Strategy Framework Directive with a special focus on Descriptor 5 (Eutrophication). The Ferry box systems has in Danish coastal waters been used sporadic along the ferry line between Oslo, Norway and Kiel, Germany in the period from 2019 to 2021. The sensors that have been tested along this ferry route include: Salinity, Water Temperature, Turbidity, Chlorophyll-a fluorescence, CDOM fluorescence, Oxygen and pCO_2 (Murray et al., 2022).

5 International outlook

A great number of ocean observation programs currently exists around the globe, with each of these having different objectives and setups. Therefore, summarizing both the setups as well as the experiences and knowledge gained from these programs are far beyond the scope of this short report. We have therefore below only highlighted some few interesting programs, which highlight the experience and knowledge gained from these observation systems (**Table 3**).

Chesapeake Bay Interpretive Buoy System (CBIBS), United States – Based in Chesapeake Bay, United States the CBIBS aims to provide high resolution data in real time (Wilson, 2009). The program was initiated in 2007 and currently has 11 buoys in operation. The sensors installed on these buoys currently detect changes in the following parameters: Air temperature, barometric pressure, wind direction and speed, current direction, current speed, wave direction, wave height, wave period, salinity, water temperature, turbidity, chlorophyll-a fluorescence and oxygen. The program has furthermore tested the use of nutrients sensors, but these are not deployed on a routine basis.

Integrated Marine Overserving system (IMOS), Australia – Since 2009 nine national reference stations scattered around the Australian coast has under this program been deployed to monitor changes in the environment (Lynch et al., 2014). Sensors are installed on the buoys to follow changes in the following environmental variables: Wind Direction and speed., Pressure, Conductivity, Salinity, Water Temperature, Turbidity, Chlorophyll-a fluorescence, Oxygen, Red wavelength scatter. Furthermore, at some sites also pH and fCO^2 sensors installed. The program has furthermore made initial trials of nutrients sensors, but these are not deployed on a routine basis.

Western Channel Observatory , *United Kingdom* – Two stations in the English channel on the south-west coast of the United Kingdom has been visited since 1903 to follow changes in the physical, chemical and biological environment (Smyth et al., 2015). The stations have since 2009 had a bouy with sensors installed in order to provide hourly measurements of the following variables: sea surface temperature, salinity, oxygen, turbidity, chlorophyll fluorescence; CDOM fluorescence, nitrate and PAR. The data are transmitted every three hours to the base laboratory to provide data in near real time.

Coastal Observing System for Northern and Arctic Seas (COSYNA), Germany – The focus regions of COSYNA program is the German Bight in the North Sea and the Arctic coast of Svalbard. The program uses a range of platforms including remote sensing, ocean gliders, cabled underwater observatories, ferry box systems, buoys and measuring poles (Baschek et al., 2017). The buoy sensors used as part of the program include temperature, salinity, chlorophyll fluorescence and pH. Nutrients (Ammonium, nitrate/nitrite, phosphate and silica) are as part of the program analysed using a sequential injection analysis (SIA) installed on a Ferry box system. The program furthermore uses Automated Filtration Systems (AUTOFIM) for automated collection of samples for molecular analyses and they furthermore have developed an in-situ imaging system for zooplankton identification (Baschek et al., 2017). In addition are both active and passive samplers installed to study micro pollutants.

Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS), United States - Since its initiation in 2009 the NERACOOS network has run buoys along the northeast coast of the United States (Morrison et al., 2012; Twardowski et al., 2015). These buoys are complemented by sensors installed on autonomous gliders and vessels. Currently the sensors used as part of the program include: temperature, salinity, chlorophyll fluorescence, acoustic doplar current profilers (ADCP), oxygen, pH, ammonium, nitrate and phosphate. The sensor based nutrient monitoring is still being refined and we here show some of nitrate data obtained as part of the network (**Figure 10**).

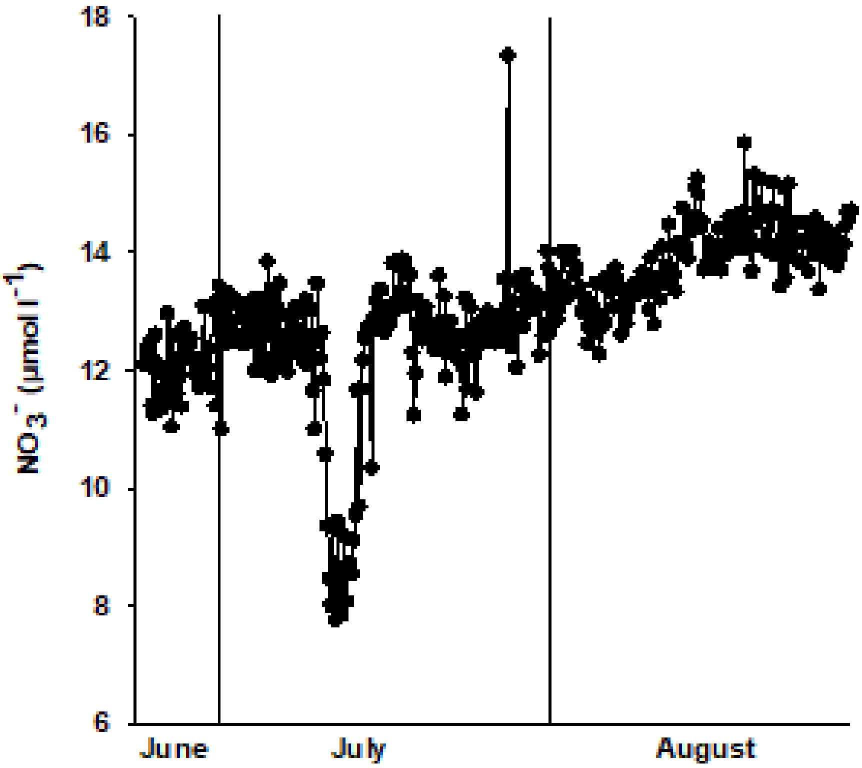


Figure 10. Example of nitrate (NO3-) concentrations (in µmol l-1) in the Gulf of Maine, United States obtained in the period June to August 2013 obtained with a SUNA V2 Nitrate Sensor (measurement every 6 hour). The full black lines indicate the change in month. These data were obtained from the data portal on Northeastern Regional Association of Coastal Ocean Observing Systems homepage (http://www.neracoos.org/).

Table 3. Overview of some operational ocean observing systems existing around the world.

Country	Program name	Responsible institute	Focus region	Key sensor parameters measured	Operational (Y/N)	Homepage
United States	Chesapeake Bay Interpretive Buoy System	National Oceanic and Atmospheric Administration	Chesapeake Bay	Air temperature, Barometric Pressure, Wind direction and speed., Current Direction, Current Speed, Wave Direction, Wave Height, Wave Period, Temperature, Salinity, Turbidity, Chlorophyll a fluorescence, Oxygen, Nitrate (sporadic)	Y	https://buoybay.noaa.gov/
Australia	Australia's Integrated Marine Observing System (IMOS)	Multi-institutional program	Australian continental shelf	Wind speed and direction, Conductivity, Temperature, Salinity, Turbidity, Chlorophyll a fluorescence, Oxygen, pH (not all locations), fCO_2 (not all locations)	Y	https://imos.org.au/
United States	North-eastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)	Multi-institutional program	United States - continental shelf	Wind speed and direction, Temperature, Salinity, Turbidity, Chlorophyll a fluorescence, Oxygen. Nitrate (sporadic)	Y	http://www.neracoos.org/
Germany	Coastal Observing System for Northern and Arctic Seas (COSYNA)	Multi-institutional program	North Sea and Artic	Wind speed and direction, Temperature, Salinity, Turbidity, Chlorophyll a fluorescence, pH, Oxygen, Ammonium, Nitrate, Phosphate, Silicate (Nutrients are from Ferry box)	Y	https://www.hereon.de/institutes/carbon_cycles/cosyna/index.php.de
United Kingdom	Western Channel Observatory	Plymouth Marine Laboratory	English Channel	Wind speed and direction, PAR Temperature, Salinity, Turbidity, Chlorophyll a fluorescence, CDOM fluorescence, nitrate, Oxygen	Y	https://www.westernchannelobservatory.org.uk/

6 Practical considerations and recommendations

Below are some general practical topics that need to be considered before a sensor setup is purchased. We will in our recommendations not include: 1) the potential costs and socio-economic values of an ocean observing system and 2) how changing to a more sensor-based monitoring program will influence the capability to continue long-term time series or analysis as part of the Danish marine monitoring program (NOVANA).

Buoy and platforms:

- How many sites and depths measured are necessary to fulfil the requirements?
- Which platforms are suitable for the specific environment and which sites are most representative?

Sensors: Quality assurance, calibration, drift and biofouling:

In this section, we have outlined issues and recommendations that should be considered when a sensor is chosen, as well as when it is deployed in the field.

General considerations when choosing a sensor:

- Which variables need to be monitored and at which frequency?
- What are the environmental characteristics of the study sites? For some types of sensors (e.g. oxygen optodes) hydrogen sulphide (H_2S) and other chemicals (e.g. SO_2) are damaging, and these sensors are therefore not ideal for use in low O_2 environments. In addition, some sensors are sensitive to changes in salinity and temperature so installing these in shallow and/or environments influenced by episodic river inflow are not ideal. In addition, high levels of coloured dissolved organic matter (CDOM) can in some cases impair the function of optical sensors.
- What are the associated costs with running the sensors? The total cost includes funds for e.g., collection and analysis of validation samples, pre and post deployment calibrations, factory recalibrations, equipment need for ancillary data (e.g. CTDs), training needs for field personal (field, hardware, software), renewal of sensors or sensor parts.
- What are the setup and technical requirement needs? This includes e.g.: requirements for measuring frequency, deployment length, battery lifetime, cables, antifouling protection and deployment platforms.
- Can the sensors measure within the ranges required and with the precision needed? As an e.g. can optical Nitrate sensors only be used with confidence at locations with high concentrations.

Considerations during pre- and post-deployment:

- Calibrations:
    - Pre- and post-deployment calibration of sensors should be performed. All sensors drift over time so there is a need for pre-deployment calibration, post deployment calibration and in situ calibration (e.g. atmospheric zeroing). This information will be

essential for data processing and for determining how well the sensor works.

  - For some types of sensor types (e.g. oxygen) temperature and salinity is important and it therefore necessary to monitor these during both calibration and deployment.
  - Before deployment, sensors should be checked for ambient temperature sensitivity, and they should be calibrated at temperatures close to those expected in the study region.
  - Optodes need before deployment to be preconditioned in saltwater (e.g. excited multiple times before use), which takes time (up to a 1 month). In addition, when optodes are stored and transported, foils need to be kept wet using a water-filled protection cap.
  - After calibration and before deployment all optical based sensor windows need to be cleaned using lens tissue and non-film forming detergent followed by rinsing with clean water.
  - Before deployment in the field the entire setup should be tested in the lab with all cables and battery power.
- Factory calibrations:
  - Factory calibration are many times inadequate and should be treated with caution. Therefore, these calibrations should be validated with a pre-deployment and collection of regular discrete samples over time. These discrete samples should if possible be collected at different temperatures and salinities.
  - Generally, sensor accuracy and precision as reported by the manufacturer are determined using laboratory standards and in controlled environments, so these are generally not applicable under in-situ conditions. Therefore, measurements in the field will not have the same degree of accuracy and precision.
- Biofouling:
  - Biofouling can cause disruptions to measurements e.g. by degrading membranes, hindering mechanical functioning, and for optical instrumentation, blocking the sensor's field of view.
  - Several antifouling techniques have been developed to minimize impacts, these include amongst others silicone which has a long residence time and can help slow down biofouling; an alternative is the use of copper tape placed on the sensor.
  - Regular wiping of the sensor can remove biofouling and improves optics (e.g., automatic wipers which clean the sensor on a regular time interval).
  - A comprehensive overview of biofouling prevention practices and recommendation for best practices can be found in (Faimali et al., 2016).
- Other practical considerations:
  - Before each deployment, the power requirements should be evaluated, and it should be ensured that the battery is suitable.
  - After recovery of the sensors from a deployment maintenance, checks are necessary before a subsequent deployment. In the field, the following steps should be taken: photographing the condition of the sensor, removing e.g. anti-fouling copper tape,

washing the logger, and downloading data. Back on land maintenance continues with cleaning the sensor and assessing it for any physical damage.

- Measurements of In-situ changes in salinity and temperature are important for interpretation of results. In addition, changes in these variables can affect e.g. sensor power use and reagent crystallization. Please note that if multiple sensors are installed, it should be ensured that the clocks of each sensor are synchronized. This will allow better detection of data outliers and therefore ensure data quality.
- Optical based sensors are sensitive to how where they are mounted on the deployment device and generally, you should avoid placing them at the bottom.
- For instruments that have a tube intake it is best to use black tubing and copper tubing at the entrance to reduce biofouling.

During deployment:

- For all sensors, it is critical that discrete seawater samples are collected during deployment to ensure the quality of the obtained results. Pre- and post-deployment checks should also include validation of the sensor outputs by comparison to discrete seawater samples. If possible, take frequent water samples throughout the deployment in order to ensure that the data collected by the sensor are accurate and can be trusted.
- Following data in real-time can be an advantage as this can be used to follow sensor performance.

Data treatment:

- Data should be checked with care to identify outliers and drift which can be due to sensor malfunctioning, bobbles and/or impacts of biofouling. Sometimes atypical data points are not due to malfunctioning but are real, and therefore looking at output from multiple sensors might be necessary.
- Biofouling affects both sensor functioning and the data obtained. Therefore, it is necessary, in a consistent way, to define when to stop believing the sensor data. In general detecting biofouling issues are easier when trends from different datasets are compared. Deploying multiple sensors will therefore ensure high quality and long-term reliable results.
- Detecting biofouling issues in the dataset can help to estimate deployment durations in your environment and this information should be used to plan the duration of future deployments.
- Consider always in your data treatment, both output from the pre- and post-deployments and the results from discrete seawater samples.
- The large amounts of data obtained from a bouy, require careful and systematic processing. Data volumes in high temporal resolution are generally good, but too many uncertain and erroneous data can reduce the usefulness of data (see also (Palevsky et al., 2022). Popularly speaking, it's like drinking water from a fire hose once the data pours in. Large textbooks have been written on the handling of high-frequency data among researchers who work with meteorological data or, for example, high-frequency sound data. Based on experiences from Roskilde Fjord these simple approaches can be used to processing data, divided into six phases:
  1. Visual inspection of data when received.

2. Identify and flag potentially erroneous data, typically extreme or missing values.
3. Remove erroneous values. Either manually or using data filters.
4. Fill data gaps by interpolation, models or use of running averages.
5. Calibration in relation to supplementary ship-based measurements. Since the Roskilde Fjord buoy is located at a NOVANA station, we have used these measurements to calibrate oxygen, pH, salinity and chlorophyll.
6. Correction for sensor drift. All sensors generally drift over time. It is typically seen by a gradually decreasing signal and can be identified and corrected by comparing data immediately before and after servicing and calibration. The problem with sensor operation is less for measuring probes that automatically wipe the sensor heads clean.

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