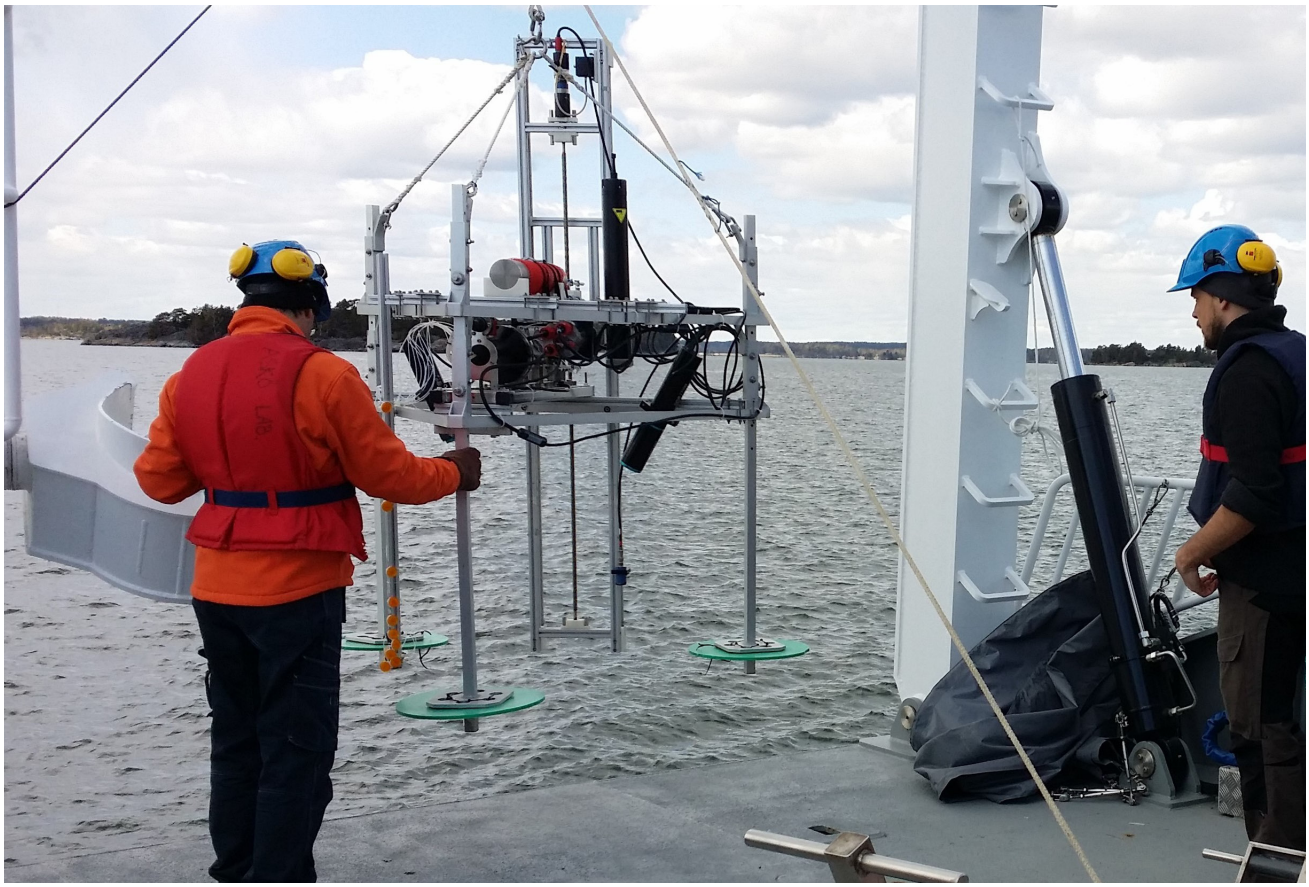
Stockholm University

Bachelor Thesis

Degree Project in Geochemistry 15 hp

Investigating the Benthic Boundary Layer Using an Autonomous Lander in the Baltic Sea: A Proof of Concept

Jonas Fredriksson



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Investigating the Benthic Boundary Layer Using an Autonomous Lander in the Baltic Sea: A Proof of Concept

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Stockholm 2017-06-01

Abstract

The benthic boundary layer is a dynamic zone where the water column transitions into the sediments. Oxygen availability, relatively high amount of suspended particles, and nutrient leakage from the sediments ensures that carbon mineralisation and denitrification rates can be high, sometimes even on par of with those of the sediments. Furthermore, the benthic boundary layer controls the transport of re-released nutrients from the sediments back into the water column. Which is of significance for investigating the nutrient cycles and eutrophication. We show how this environment can be accessed and sampled using an autonomous benthic lander system. A lander has the advantage that it can sample the bottom water directly providing an integrated view of the processes taking place in the sediments. It can also collect data on exchange between the sediments and the water column in environments where normal coring methods do not work. A benthic lander can also support many different sensors and sampling devices.

A lander and sensor setup was assembled. The individual components underwent maintenance, broken parts were replaced, and sensors were calibrated. A user manual covering all components and software was produced. Finally, a proof of principle field test to evaluate the quality of the data was performed at The Fifång Deep in mid May 2017.

Supervisor: Volker Brüchert

Introduction

Background

Since the start of the industrial revolution humans have had an ever-increasing effect on the various elemental cycles. The carbon cycle has been affected with the exhumation and subsequent remineralisation of coal, oil and gas. The nutrient cycles have been similarly affected, e.g. by mining of phosphorous to be used as fertiliser and by the industrial Haber-Bosch process that converts unreactive dinitrogen gas and hydrogen gas into bioavailable ammonia. Both phosphorous and nitrogen are essential nutrients and are added as fertilisers in the forms of ammonia and phosphate. These soluble species will eventually end up in the groundwater and from there, through rivers and waterways, into the sea. The Baltic Sea is an example of a water body whose catchment area presently have 85 million people living in it. Adding nutrients to the waters that discharge into the Baltic will increase productivity of phytoplankton (photoautotrophs) and those that feed upon them (heterotrophs). This will also lead to an increase in sedimentation rate as dead organic matter settles to the seafloor. The organic carbon can then be remineralized as heterotrophs living in the sediments use various electron donors to oxidise it. Re-releasing the nutrients which will ultimately sustain primary productivity. Since primarily and ultimately oxygen is consumed in these reactions a high sedimentation rate of organic matter is intimately coupled with seafloor anoxia.

Anoxia and phosphorous recycling

Once anoxic conditions are reached trying to hinder eutrophication by limiting the nutrient input is not effective any longer. This is related to the fact that under anoxic conditions iron changes its redox state from insoluble Fe(III) to soluble Fe(II), and subsequent FeS_2 formation. Oxidised iron can sorb phosphate to its surface (Sundby et al., 1992) thus immobilising the phosphate in the sediments and keeping it from being recycled into the ecosystem. However, should the iron change oxidation state and be dissolved then the previously sorbed phosphorous will be bio-available once more. Nitrogen adds another layer of complexity to this story. Since it is not only an essential nutrient that all cellular organisms need to build their bodies but can also often serve as an electron acceptor. The fact that nitrogen has 8 possible oxidation states (-III - +V) serve as an indication of how many reactions it can participate in and the complexities that this adds. When microbes use nitrogen as electron acceptor and carbon as electron donor, this happens in the absence of oxygen, the end-product is dinitrogen gas. Nitrogen is stepwise transformed through $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$, where the dinitrogen is basically inert and lost as a gas. Nitrogen loss can also occur through the process of anammox, anaerobic respiration of ammonia, $NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$ (Mulder et al. 1995). This is a chemolithoautotrophic process. This process has been observed to occur in many sediments as well as in oxygen minimum zones of the water column (Gruber 2004).

The Redfield Ratio and eutrophication

At first sight nitrogen loss seem like an eutrophication inhibitor. Since availability of any essential nutrient puts a hard cap on productivity. If any essential nutrient is lacking primary productivity stops. Whether this lack is due to lack of nitrogen, phosphorous, iron or silica does not matter. It has been shown that marine microorganisms on *average* use 106 moles of carbon for every 16 moles of nitrogen, and every 1 mole of phosphate in their biomass (Redfield et al. 1963). This observed relationship is called the Redfield Ratio. Denitrification drives the relative abundance of C:N:P limits the possibility for most organisms to grow biomass and reproduce. However, there are a few dinitrogen (N_2)-fixing organisms that can break the strong triple bond of native dinitrogen and use dissolved nitrogen gas directly. They will flourish under “high P-- low N” conditions (Capone and Carpenter 1982) since they, even though they must expend a lot of energy in fixing nitrogen, will

have no competition. A famous and noteworthy example of an organism capable of nitrogen fixation are the filamentous cyanobacteria of the genus Trichodesmium. When they eventually die and decompose they will release bioavailable nitrogen previously fixed, moving the equilibrium towards Redfield. Enabling other species that require close to Redfield to flourish.

Denitrification rates, water sampling, and coring.

Three classical ways of studying and quantifying these interactions between sediments and water are 1) through coring and porewater retrieval (Schulz 2000) 2) through microsensors (Jørgensen and Revsbech 1985), and 3) through benthic box techniques (Tengberg et al., 1995). Porewater methods have a low vertical resolution and are sampled in vitro. Calculating fluxes from porewater gradients also require assumptions regarding the diffusion coefficients in the sediments (Berg et al. 1998). Microsensor, on the other hand, have very high spatial resolution and can be used to probe the diffusive boundary layer of water just above the sediments. Calculating absolute fluxes from concentration gradients in water doesn't rely on as many assumptions as diffusion in sediments, i.e. more reliable. However, they fail to consider advective fluxes due to burrowing fauna which in some circumstances are of the same order of magnitude or even higher than the diffusive flux (Glud et al. 1994). Small scale topography can also create lateral pressure gradients that creates small scale local advective fluxes. A way of trying to overcome or work around these issues are by sampling the water layer directly overlaying the sediments, the so called benthic boundary layer. It is a loss in fine scale resolution but it serves to integrate all the various sources. Benthic box techniques do this but also beg the question whether the water movement and exchange is influenced by the container.

The Benthic Boundary Layer (BBL)

The benthic boundary layer is defined as the water layer overlaying the sediments themselves. In this layer, the water velocity changes from that over the overlying water column to zero or close to zero if the sea bed is covered by mobile particulate matter, e.g. in erosional environments. The physical properties of this layer are governed by shear stress between the water column moving over the

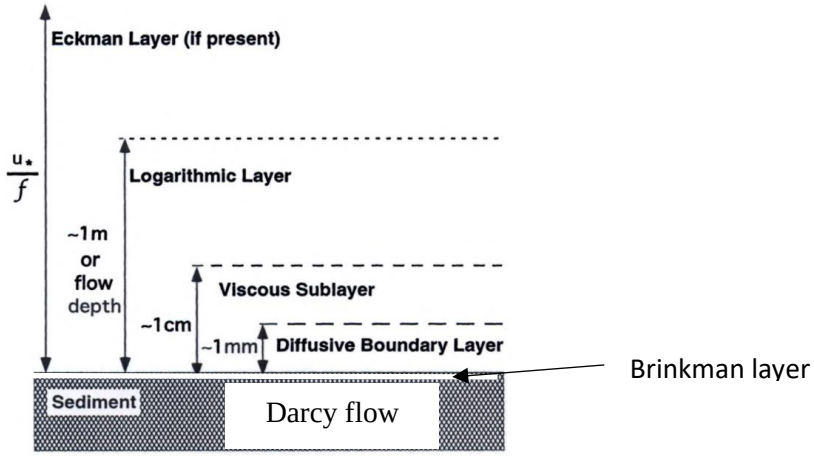


Figure 1: The sublayers of the benthic boundary layer. Reproduced from Boudreau and Jørgensen (2001).

sediments as well as relative movement between different water layers. This shear gives rise to turbulence and the eddies formed can resuspend sediments, help keep suspended particles in suspension, and break apart flocculates. The water behaviour changes depending on current strength and the distance to the sea floor. Several sublayers can be defined based on the physical properties. These divisions into layers are somewhat artificial and the transitions between them are continuous. How these layers are defined and where the borders are placed depend somewhat on what properties you are interested in investigating.

Figure 1 shows how the benthic boundary layer can be further divided into sublayers:

- The logarithmic Layer or the Outer Boundary Layer
- The viscous layer
- The Diffusive Layer

The logarithmic layer is characterised by turbulent mixing, eddy formation, and the mean flow is frequently given by the "law of the wall relationship":

$$U(z) = \frac{u_*}{k} \ln \frac{z}{z_0}$$

where U is the velocity, u_* is the friction velocity, k is the von Kármán's constant, and z_0 is the roughness length. Closer to the sediments where internal friction rivals eddy mixing a viscous sublayer exists. Even closer to the sediments, as the current velocity approaches 0, mixing is dominated by molecular diffusion. If the sediments are sand then a convective Brinkman layer can arise at the top millimetres. Beneath this layer any flow in permeable sediments will obey classical Darcy flow.

Pope (2000), who also describes a buffer layer as an intermediate layer which is a transit layer between the viscous layer and the log law dominated layer, found that a 10 cm/s current 1 m above the sediment surface causes the upper boundaries to be at 1 cm, 1 mm, and 100 µm for the buffer layer, the viscous layer, and the diffusive boundary layer respectively. If the current velocity is decreased to 1 cm/s the upper boundaries are found at 10 cm, 1 cm, and 1 mm respectively. How well developed the layers are depends greatly on current velocity. It should be noted that due to the interaction between frictional and inertial forces flow spirals, reverse Ekman spirals, arises and the net transport in the BBL is not in the same direction as the free-flowing movement of the water column above (Ekman 1905)[1].

The benthic boundary layer exhibit strong oxygen and nutrient gradients as oxygen, as the final electron acceptor, is consumed in the sediments and nutrients are released from them. This combination of an oxidised bottom water environment together with the release of reduced components from the seabed, and high amount of suspended particles creates a very dynamic region. In fine-grained sediments, the availability of nutrients and electron acceptors are limited by the diffusion rate, which generally is low. In the thoroughly mixed benthic boundary layer, however, diffusion limitation is removed and turbulent transport ensures high supply rates. The benthic boundary may therefore be a significant source for carbon mineralisation and denitrification, a water compartment that is overlooked and not quantified using coring or box techniques. To summarise, the transport of and transformation of nutrients and oxygen across the BBL controls the availability of nutrients for the primary producers in the photic zone. Microbial activity in the BBL itself cannot be overlooked nor can the effect of irrigation and bioturbation. This leads to the idea of sampling the BBL itself. The normal way of sampling the water column is by vertical Rosette samplers. However, due to technical reasons they cannot be used this close to the seafloor nor do they provide the resolution needed to resolve gradients in the BBL.

A benthic lander provides a way of circumventing some of these problems. It provides a sensor framework that can perform non-invasive in situ measurements of the benthic boundary layer. Thus, bridging the gap of our understanding of the sediments and the water column. A lander can be

[1] This is exactly the same principle as in Ekman spirals where the net transport of near surface currents is at an angle relative to the prevailing wind direction.

placed on seafloor where normal methods do not work such as sandy sediments, mussel banks or where very thin sediments overlies bedrock. In addition, probing the benthic boundary layer provides an integrated view of the water-sediment interaction thus accounting for contributions from burrowing organisms and macro-fauna.

Project aims

This project will deal with 1) The assembly of a benthic lander and its components. 2) Maintenance, repair, calibration and programming of the components. 3) The production of a comprehensive manual covering all components and controlling software 4) Finally, the lander and its component setup will be field tested at the Fifång Deep north of Askö in the Trosa archipelago.

The components will consist of: A tripodal lander, a peristaltic pump, a motor controlled elevator, two oxygen optodes, a camera and a LED system, an Aquadopp current profiler, a central steering device, and a battery. At the end of the project all components will be in good working order. They will have undergone maintenance. Broken or damaged parts will have been replaced or repaired. The sensors will be calibrated and the steering unit will be programmed with a versatile, easy to adapt code, customised for benthic boundary layer research. The manual will be written so that a nonexpert will get an understanding of how to assemble, run, and maintain the lander and all the components. The manual will be supplied in the appendix of a report describing the results of the field test at Fifång.

Methods

Overview of experimental setup

The BBL-lander consists of a three-legged aluminium frame. To this frame, several instruments were attached. This lander setup consisted of two oxygen optodes, a motor driven movable frame (the “elevator”); an Acoustic Doppler Current Profiler (ADCP); a peristaltic pump connected to a rack with 12 syringes for water samples; and a camera with an external led-light source (Figure 2). The camera, the LED-light, and the ADCP was working autonomously with their own programs and battery. The

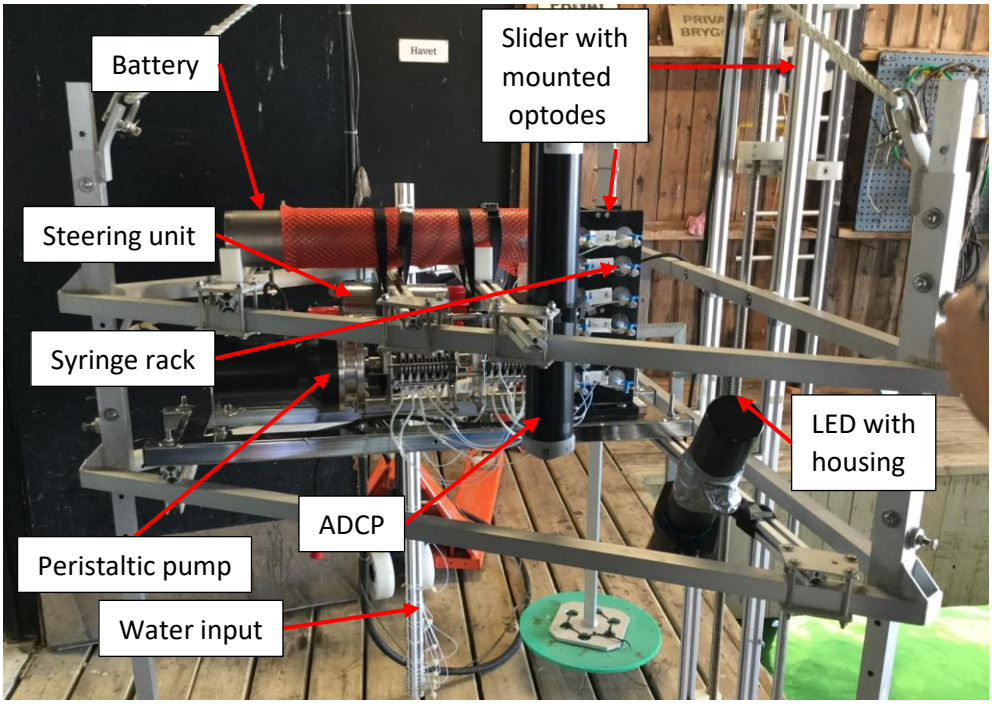


Figure 2: A benthic lander with components to: measure oxygen concentrations, current velocities, and to retrieve water samples from the benthic boundary layer.

motor driven movable frame, the optodes, and the peristaltic pump was controlled by a pre-programmed steering device. The steering device also distributed power to them with energy from an external lithium battery. Only 10 of the 12 syringes were connected for the field test.

Assembly and placement

When all equipment was attached, the lander was lifted by a rope and suspended in the air. To ensure a gentle landing and a straight "posture" the lateral positions of some of the sensors were adjusted to ensure that the centre of mass was in the centre of the lander. The lander with all instruments, Figure 2 , were placed on the seafloor from the ship Electra at the Fifångs Deep. The Fifångs Deep is in the Trosa archipelago just north of Askö, see Figure 3.

Figure 3: The lander was deployed at the Fifångs Deep just north of Askö. At 58^{o} 51.276 N and 17^{o} 39.261 E. Red star marks the spot on the map. The map is taken from Lantmäteriet's webb service: https:// kartutskrift.lantmateriet.se (© Lantmäteriet, 2017).

Buoys was attached to provide lift so that the lander's feet would not sink too far into the sediments. When the lander was in position a submersible drone was sent down to retrieve footage of the position at the sea floor. From the video feed, it could be seen that the lander was standing straight, was stable, and had started its program.

Optodes

Oxygen optodes work on the principle of optical luminescence quenching. It relies of oxygen diffusing into the detector and interacting with (quenching) a luminescent molecule. The signal from the quenched molecule is compared to a reference signal and the oxygen saturation is calculated. The two oxygen optodes were calibrated using a two point (0%, 100%) oxygen saturation calibration. One optodes was mounted on a vertically movable frame. The motor driving the moveable frame was calculated to lower and raise the frame according to a set schedule. After moving the frame to a new position the optodes conducted 10 measurements, one every 30 seconds. The purpose was to retrieve several measurements from each position to investigate the timeframe required for stable readings and if it was possible to detect any sensor drift. It is important to get stable readings quickly to improve temporal resolution in the measurements and to minimise detector uptime to save energy for long deployments. The second optode was set to collect data at a fixed point, 20 cm, above the sea floor. The optodes were set with a frequency of 1 Hz but every output averaged the last 30 s interval of data. The elevator mounted optode was programmed to retrieved data from 100, 80, 60, 40, 20, 16, 12, 8, 7, 6, 5, 4, 3, 2, 1, and 0 cm relative the seafloor. The optodes were programmed to wait for the elevator before performing any measurements. The stationary optode was programmed to collect data simultaneously with the elevator mounted optode.

Water samples

Water column

The water column was probed prior to both lander deployment as well as lander retrieval. Continuous water column data prior to placement was gathered with a Seabird 911 CTD. That provided data on dissolved oxygen, temperature, salinity, and turbidity. The water column samples during lander retrieval were collected using a Niskin bottle, with a sample collected every 3 meters. Samples for methane and nitrous oxide were collected in Labco Exetainers®, samples for alkalinity were collected in acid washed plastic bottles, and samples for nutrients were collected in pre-prepared test tubes. All containers were rinsed with the water sample itself and the test tubes were also heated post retrieval in an oven to 60 ^{o}C, for an hour to kill of most microbes. Nutrient analysis was performed five days after retrieval by The Department of Ecology, Environment and Plant Sciences (DEEP) at Stockholm University. The water was analysed for nitrite, nitrate, ammonium, phosphate, silicate, total nitrogen, and total phosphorus. Remaining water samples were stored at 6^{o}C.

Bottom water

10 syringes were set in a rack on the lander and connected to a series of hoses that were run through the peristaltic pump. The inlets for the water was placed at different heights, with higher resolution closer to the bottom. Finally, 0.4 µm filters were fitted to the ends. The filters were to keep out particles and minimise biofouling of the hoses and syringes. The hoses and syringes had been acid washed to remove residual contamination from previous deployments. To avoid gas contamination and to ensure smooth operation of the pump, the syringes and hoses were prefilled with a small, known, amount of milli-Q water. The pump was programmed to run for 13 minutes, enough to completely fill the syringes.

ADCP

The current profiler used in this field test is an Aquadopp Hr-profiler (Nortek, Norway). The ADCP was attached in the center of the tripodal lander and set facing downwards. Its internal compass was recalibrated when the ADCP was attached to the fully assembled lander. The sensor head was 96 cm above the top of the lander's feet and programmed to measure 29 water layers, each 3 cm thick. The first 9.6 cm from the profiler's head could not be read due to "ringing" of the transducer. The ADCP was set to measure with one pulse per second with a frequency of 2 MHz for the whole deployment. Having the ADCP set up inside the lander runs the risk of interference from lower parts of the lander itself influencing both the doppler beam and the currents. The water velocity data was postprocessed and analysed using Nortek's SeaReport software.

Camera

A GoPro 5 camera and a See Star LED was set in a pressure housing GPH2-1750 from GroupBinc. The camera was positioned at one end of the tripod facing downwards at an angle and the LED was set up opposite at an opposing angle to provide operating light. The camera and light was positioned to include the sea floor, the lowest part of the movable frame, and a lander leg. The intent was to observe the landing, the positioning, how far the legs sank into the sediments, and the presence of wildlife. The LED was programmed to turn on and off so the light would not affect the observations of more mobile species. Footage from the camera was stored on a micro SD card, transferred to a computer and edited using Quik™ Desktop. The camera only had enough battery to collect video for the first two hours.

Results

Water column data

The pre-lander-placement CTD data that was retrieved has been collated in Figure 4. It shows oxygen (mg/l), temperature (°C), Salinity using the practical salinity scale, and Turbidity in Nephelometric Turbidity Units (NTU). The rosette sampler measured on its way down and on the way up. No strong gradients can be distinguished but there is a small oxygen gradient from around 20 meters' depth and downwards. At about the same depth there is also an increase in turbidity. There are some large variations just at the surface as well.

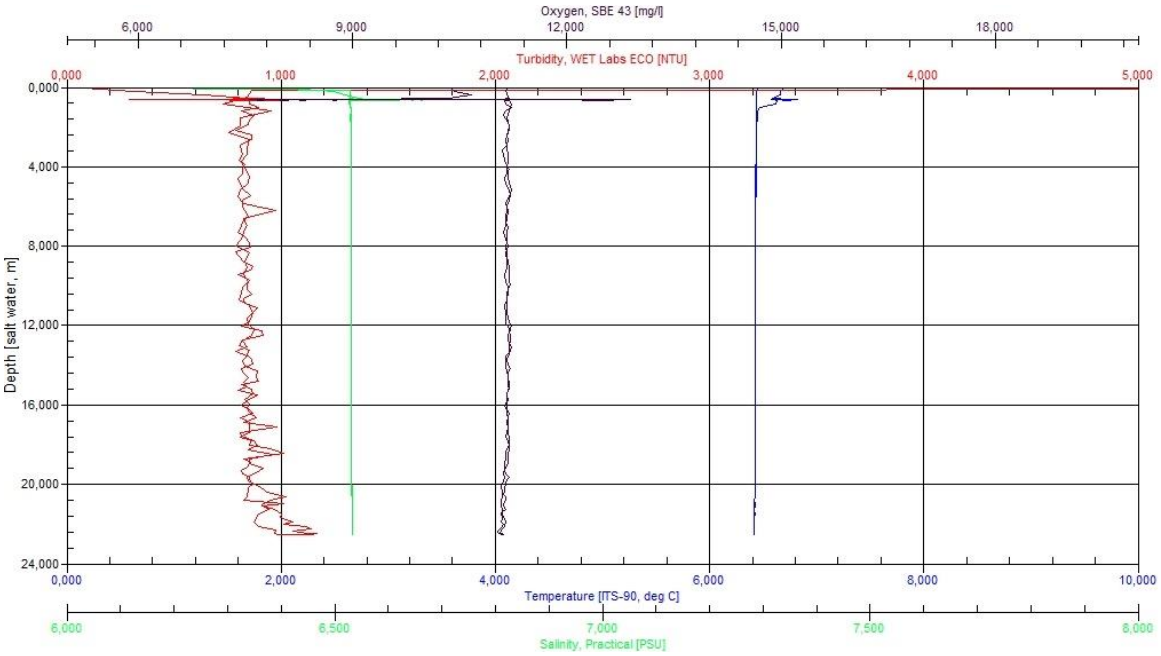


Figure 4: CTD data collected at Fifång 2013-05-10, half an hour prior to emplacing the lander. Data was collected with Electra's rosette sampler. Data was analysed and plotted using Seabird's Seasave software.

The CTD data that was collected during retrieval was measured by a handheld CTD probe on deck in water collected with Niskin bottles. Oxygen (mg/l), temperature (°C), and Salinity (‰) were measured, Figure 5. The same scale bar is used for all variables but it should be implicitly understood that the units are different. Temperature, oxygen concentration and salinity exhibits gradients all the way from the surface. Dissolved oxygen and temperature decreases with depth. Salinity increases slightly with depth. Bottom water samples were not retrieved.

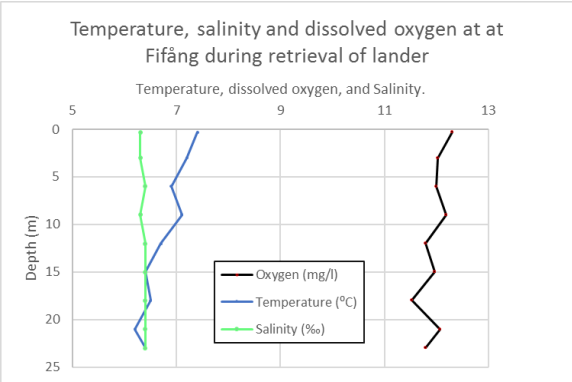


Figure 5: CTD data collected at the Fifång Deep, 2017-05-12, half an hour prior to retrieving the lander. Water was retrieved with a Niskin bottle and analysed using a handheld CTD.

Video data

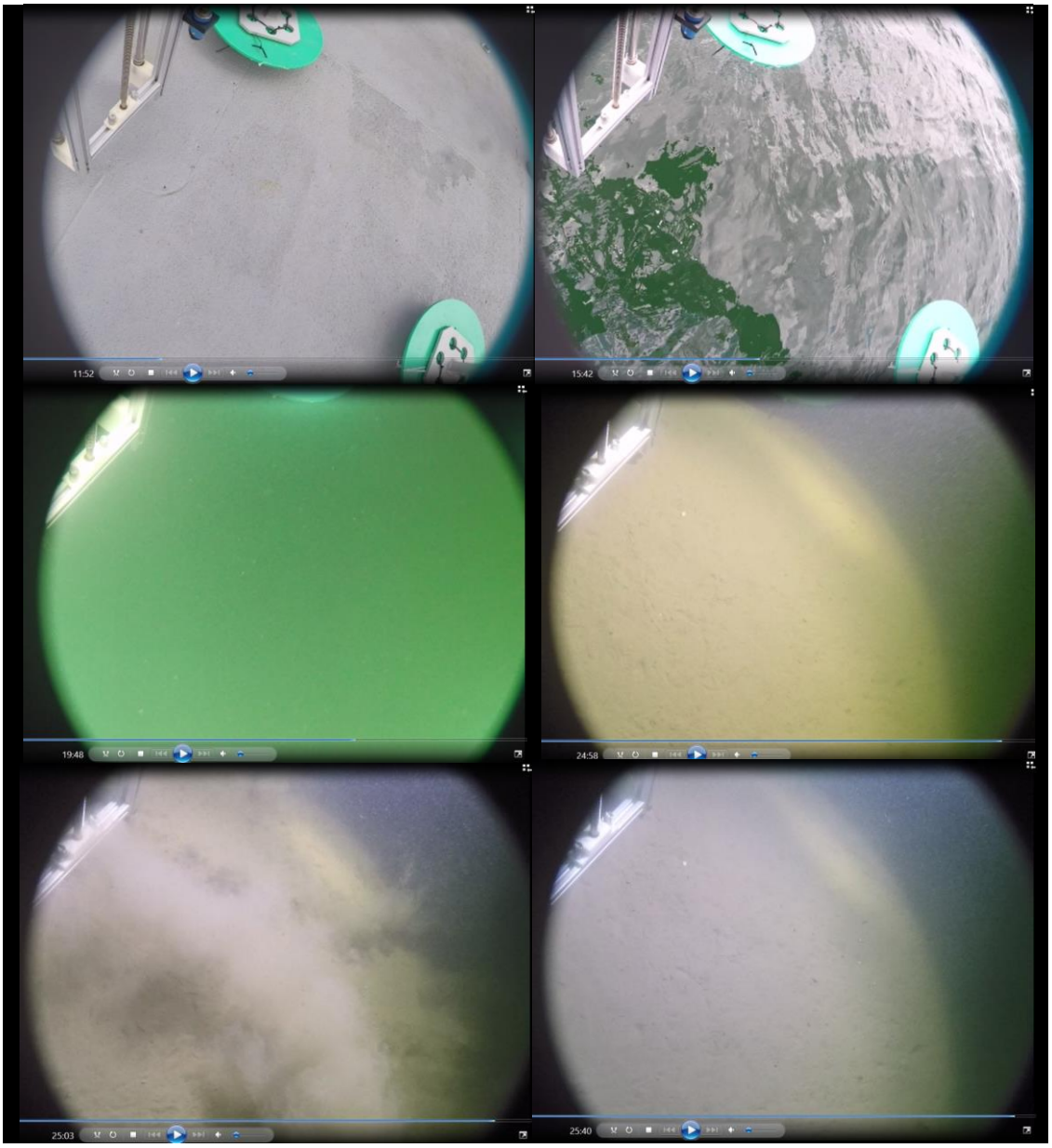


Figure 6: Footage from the lander. The timer is relative from the time when the camera was turned on.

The camera had to be started by hand on the ship. So, there is data from when the last parts of the lander are assembled, the placement, and when it was operating. From Figure 6, above, it can be seen how inserting it into the water changes the field of view, how much the sediments are disturbed and how long it takes for conditions to return to normal. The camera had enough battery for 2 hours. During this time, no wildlife was observed.

Optode data

Figure 7 to Figure 9 shows how the oxygen concentrations and temperature change with time at the various positions. The last picture in Figure 9 show how these variables change for the stationary optode. Since the stationary optode collected data at the same time as the mobile optode this data set has as many data points as all the other figures taken together. The oxygen concentrations do not decrease with depth. Oxygen concentration and temperature exhibit anticorrelation for the 23 hours after that they seem correlated.

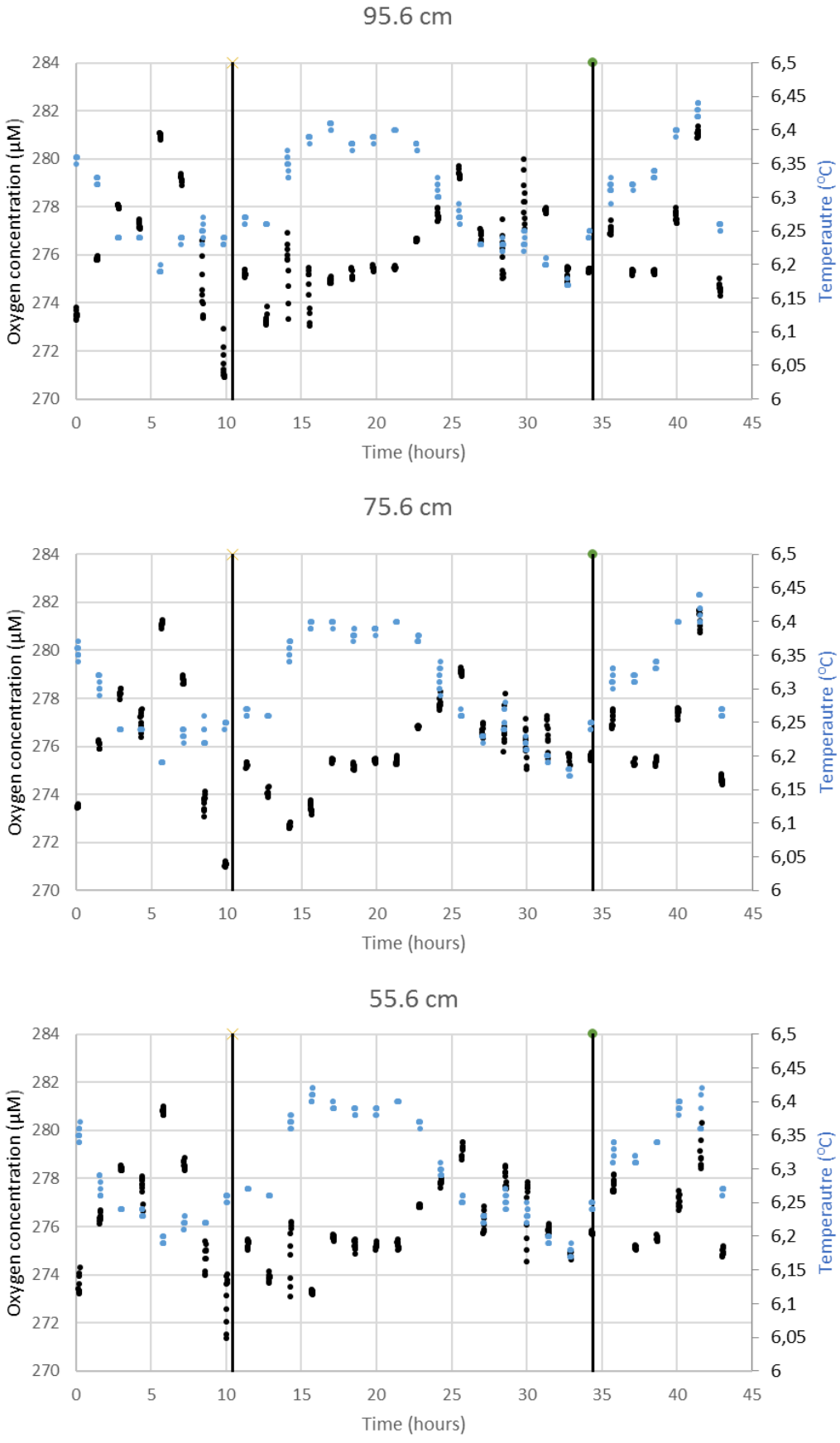


Figure 7: Optode data. Oxygen concentrations and temperature over time at various depths. The vertical black lines mark midnight. Data collection started at 13:20, 2017-05-10.

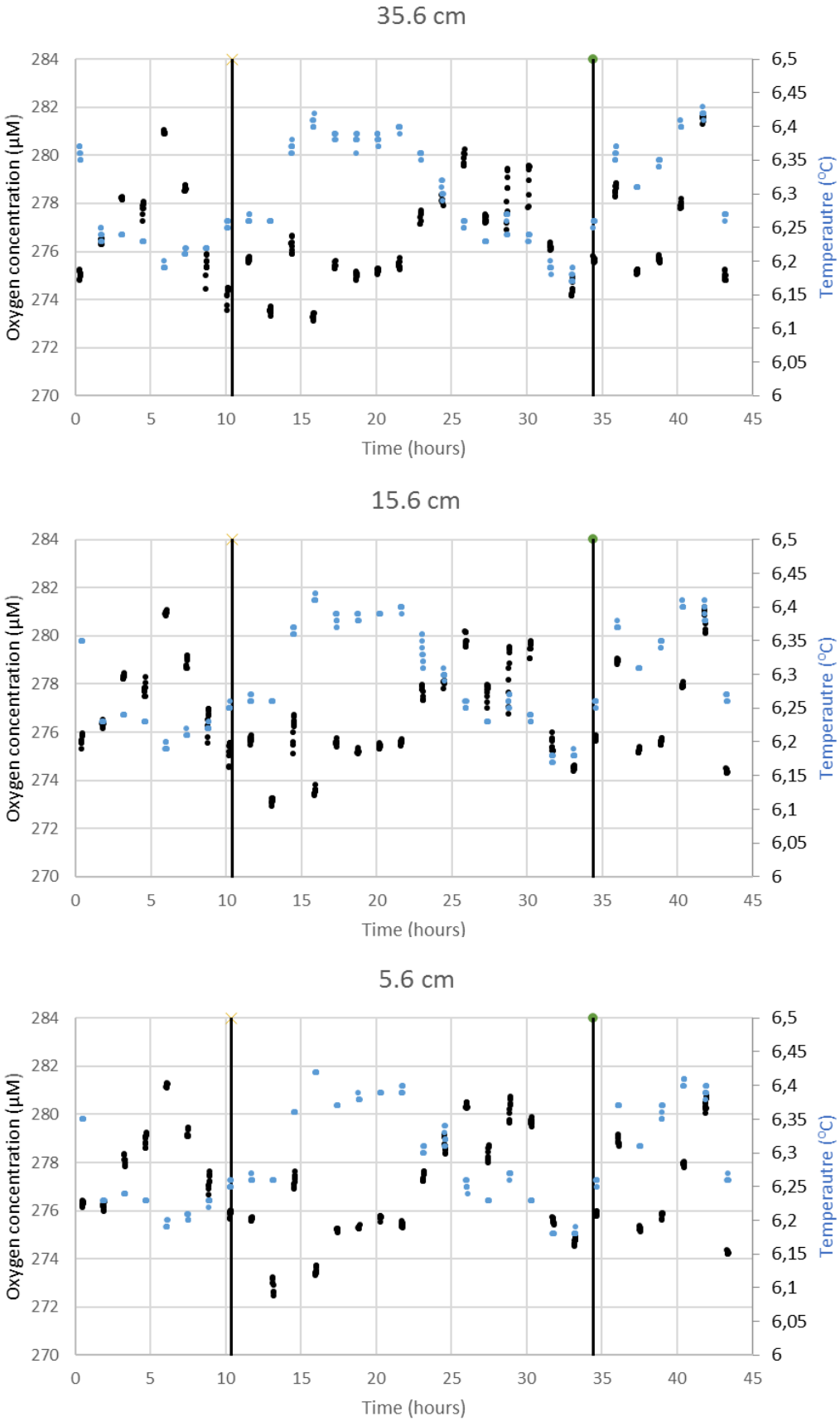


Figure 8: Optode data. Oxygen concentrations and temperature over time at various depths. The vertical black lines mark midnight. Data collection started at 13:20, 2017-05-10.

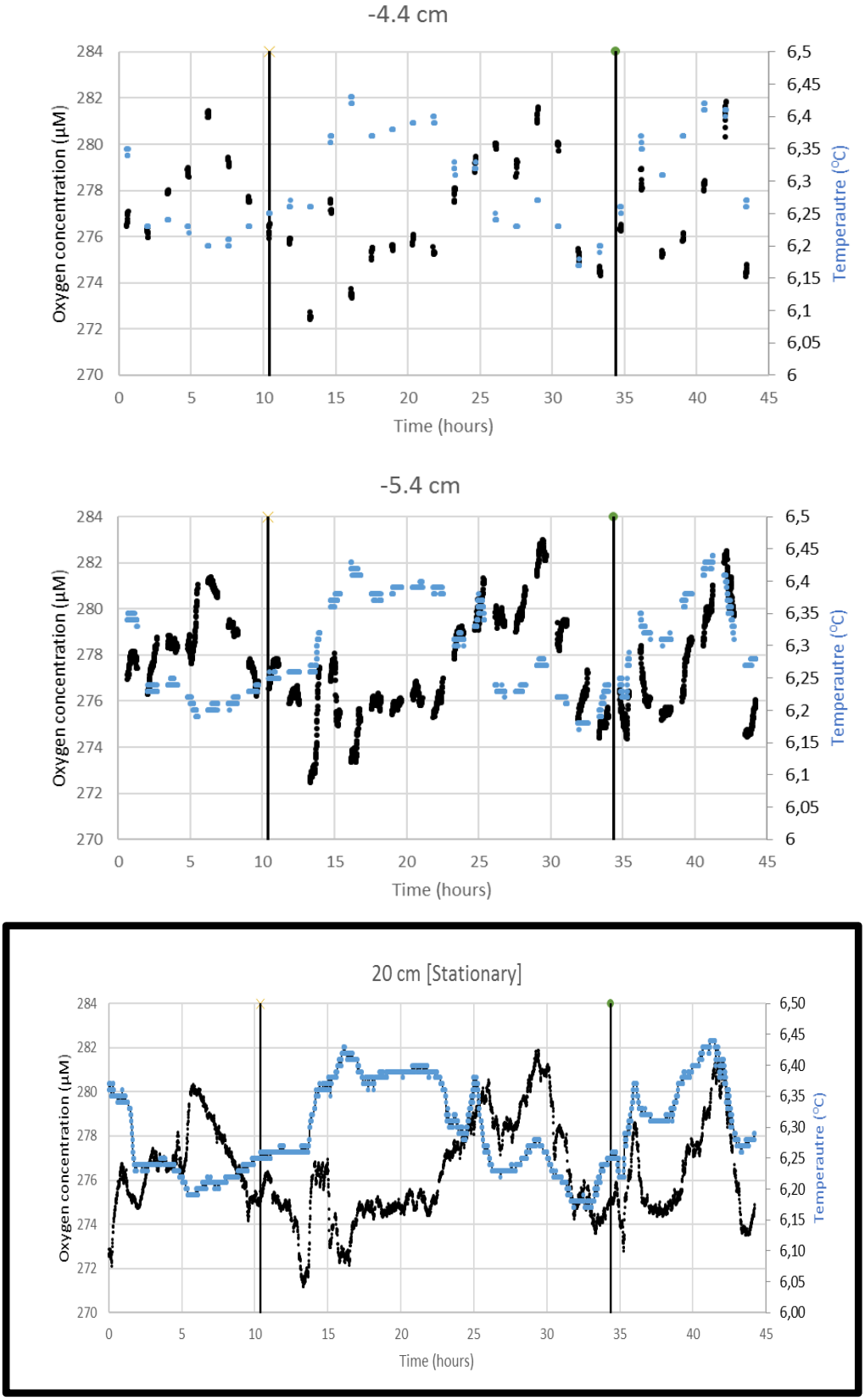


Figure 9: Optode data. Oxygen concentrations and temperature over time at various depths. The vertical black lines mark midnight. Data collection started at 13:20, 2017-05-10.

Post analysis gave that there was a small offset in calibration between the two optodes. The stationary optode was miss-calibrated. The offset has been compensated for in Figure 9.

ADCP post-processing and data

The ADCP post processing and data quality control was performed with Nortek's SeaReport software using the settings presented below. The configuration details are given in Table 1, data quality settings for postprocessing is in Table 2. The ADCP measured current velocities in 29 layers each of 3 cm thickness. The top layer is 63-66 cm above the sediment surface, the middle layer is 13-16 cm above the sediment surface, and the bottom layer is 3-6 cm above the sediment surface.

Table 1: Positional and configuration details.

Data Records	3579
Longitude	17° 39,26'E
Latitude	58° 51,28'N
Orientation	DOWN
Cells	29
Cell Size [m]	0.03
Blanking Distance [m]	0.096
Average Interval [sec]	00:00:01
Measurement Interval [sec]	00:00:01

Table 2: Quality control parameters.

Low Pressure Treshold	0
HighTilt Threshold	30
Expected Orientation	DOWN
Amplitude Spike Treshold	70
Velocity Spike Treshold	5
SNR Treshold	3

The ADCP collected current statistics for 29 water layers. It also collected information on tilt, compass direction, temperature, and pressure each second for the full deployment. Of these 29 layers 3 were analysed. The lowest water layer shown was the layer closest to the bottom were the current regime was small but ADCP gave a stable reading. The layer at 63-66 cm was the layer closest to the transducer that did not exhibit wildly swinging current directions and high turbulence. The layer at 13-16 cm was since in this layer the currents were noticeable different from the other two layers. Table 3, shows the collected current data for the chosen time and depths. The currents decrease with depth. The direction changes in a clockwise manner as the distance from the sediments increase. The exception to this for the 19-20 timeslot in which the current spiral changes direction in a counter clockwise direction.

Table 3: Collection of mean, max, min and residual current and current direction for 4 chosen times and three depths.

Time	Depth	Mean current (m/s)	Max current (m/s)	Min current (m/s)	Residue current (m/s and °)
19:00-20:00	63-66	0.31	0.43	0.18	0.30 at 165°
23:58-00:58	63-66	0.34	0.63	0.06	0.31 at 156°
08:56-09:55	63-66	0.35	0.68	0.13	0.33 at 164°
17:53-18:53	63-66	0.22	0.38	0.03	0.21 at 162°
19:00-20:00	13-16	0.22	0.35	0.10	0.22 at 168°
23:58-00:58	13-16	0.18	0.37	0.04	0.18 at 133°
08:56-09:55	13-16	0.23	0.41	0.06	0.22 at 145°
17:53-18:53	13-16	0.13	0.24	0.02	0.12 at 133°
19:00-20:00	3-6	0.04	0.09	0.00	0.03 at 177°
23:58-00:58	3-6	0.02	0.10	0.00	0.02 at 132°
08:56-09:55	3-6	0.03	0.10	0.00	0.03 at 141°
17:53-18:53	3-6	0.02	0.13	0.00	0.01 at 126°

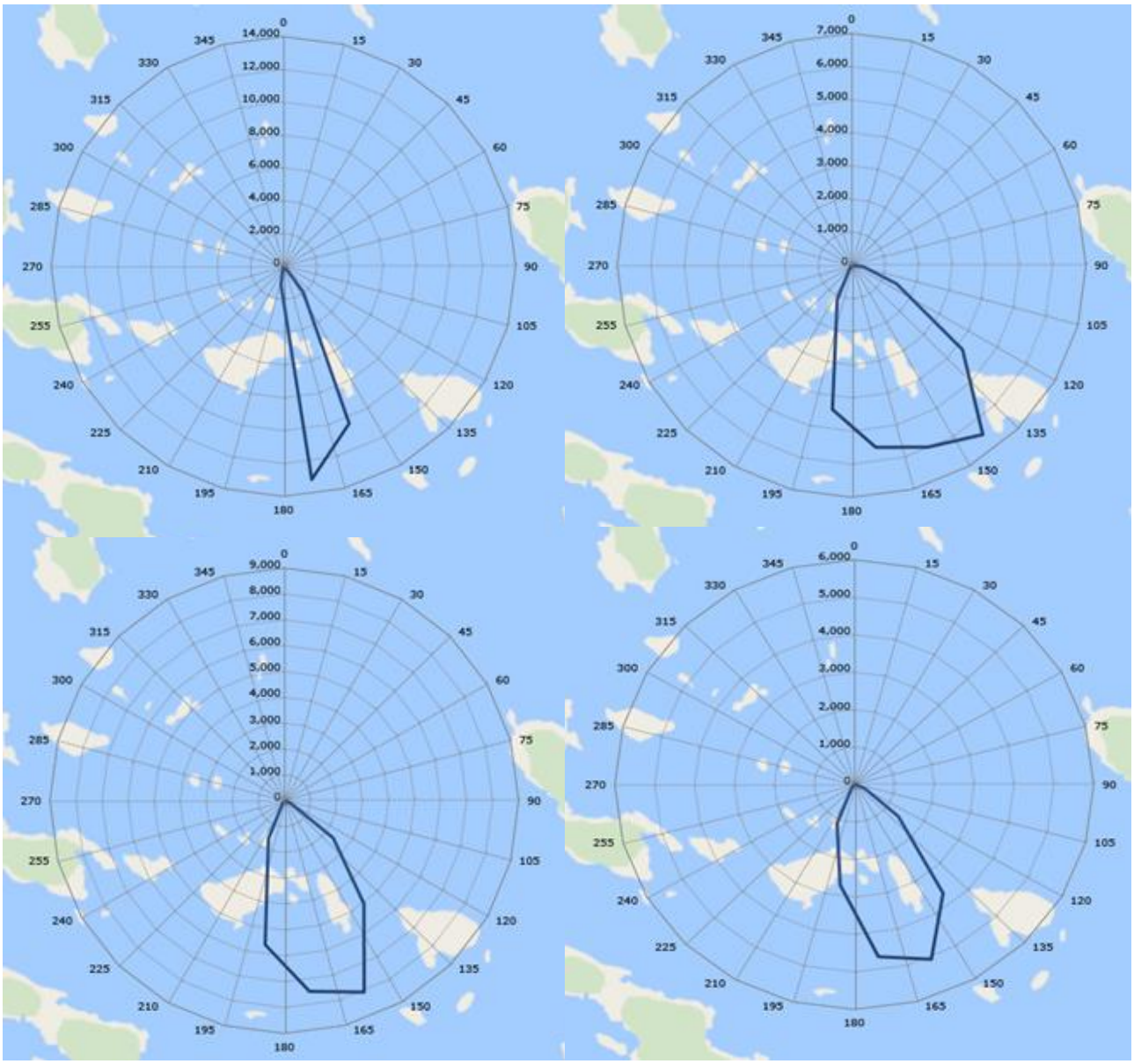


Figure 10: Current transport ($m^3d^{-1}m^{-2}$) in the layer 63-66 cm above the sediment surface. Top left is 2017-05-10 19:00-20:00. Top right is 2017-05-10 23:58-00:58. Bottom left is 2017-05-11 08:56-09:55. Bottom right is 2017-05-11 17:53-18:53.

Figure 10 shows the current transport and the direction during the designated times for the 63-66 cm layer. The current transport is measured in $m^3d^{-1}m^{-2}$.

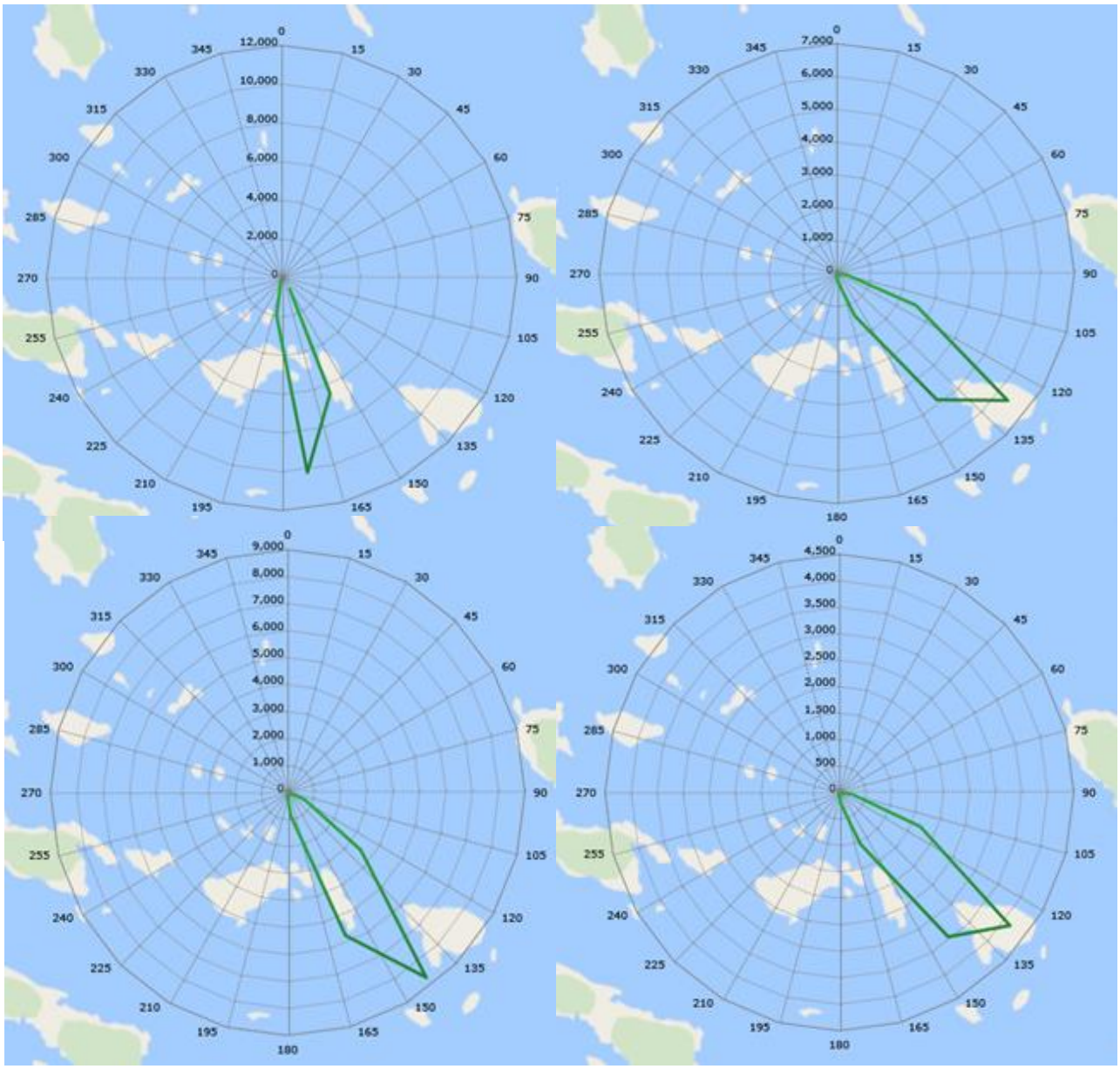


Figure 11: Current transport ($m^3d^{-1}m^{-2}$) in the layer 13-16 cm above the sediment surface. Top left is 2017-05-10 19:00-20:00. Top right is 2017-05-10 23:58-00:58. Bottom left is 2017-05-11 08:56-09:55. Bottom right is 2017-05-11 17:53-18:53.

Figure 11 shows the current transport and the direction during the designated times for the 13-16 cm layer. The current transport is measured in $m^3d^{-1}m^{-2}$.

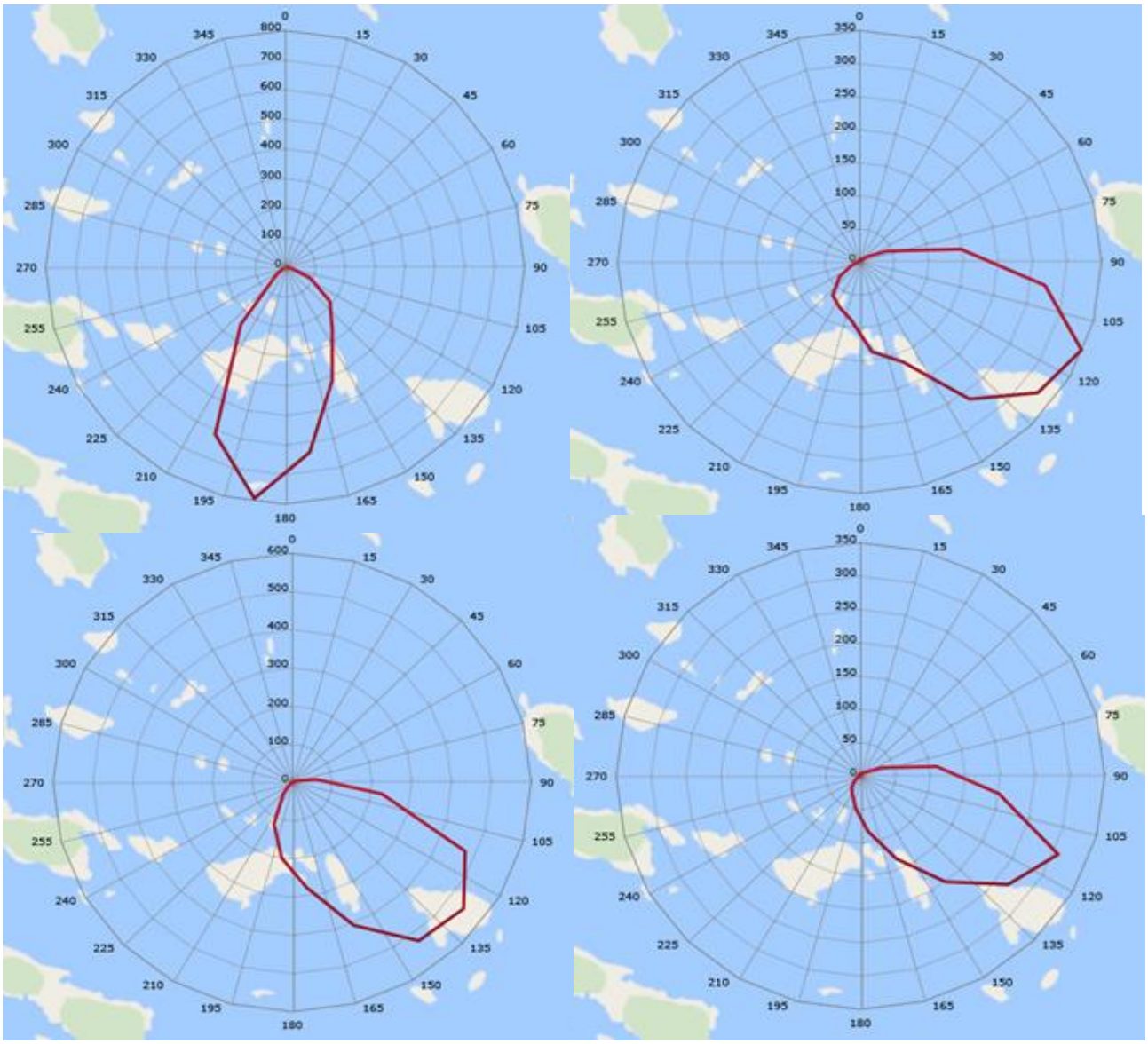


Figure 12: Current transport ($m^3d^{-1}m^{-2}$) in the layer 3-6 cm above the sediment surface. Top left is 2017-05-10 19:00-20:00. Top right is 2017-05-10 23:58-00:58. Bottom left is 2017-05-11 08:56-09:55. Bottom right is 2017-05-11 17:53-18:53.

Figure 12 shows the current transport and the direction for the 3-6 cm layer. The current transport is measured in $m^3d^{-1}m^{-2}$.

Measurement cycle and optode drift

The program controlling the elevator, optodes, and pump took longer to perform than calculated, Figure 13 top, shows how the measurements cycles increase, almost linearly, with time even though

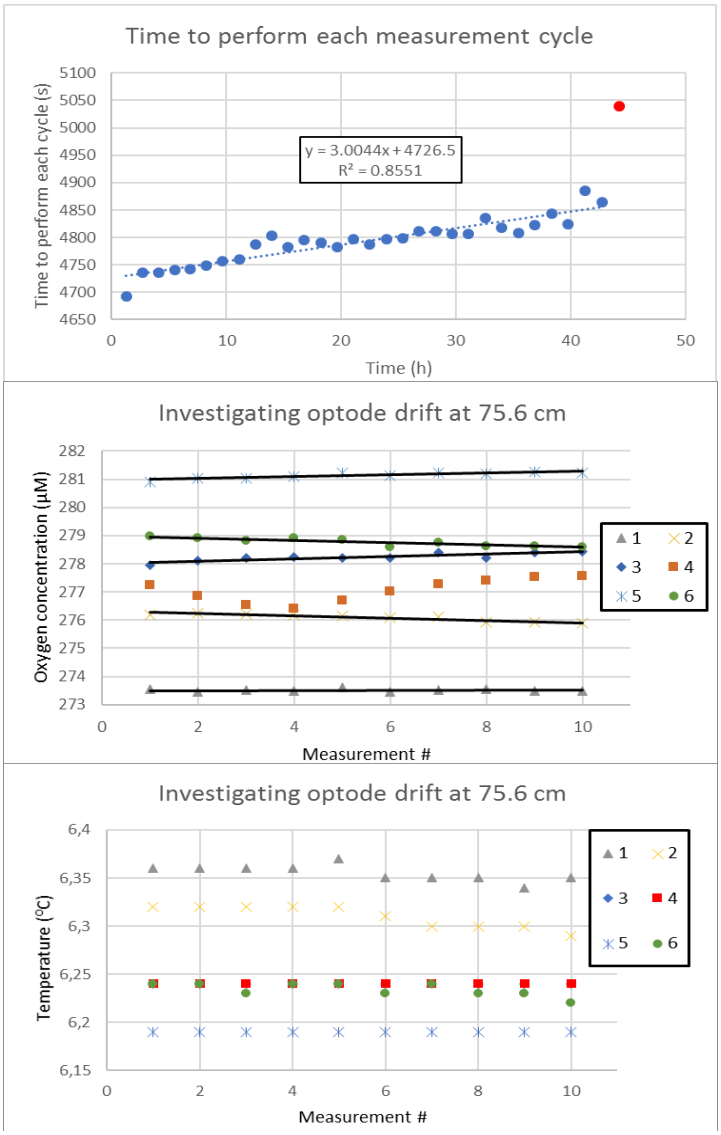


Figure 13: The figure on the top shows how the time for a whole measurement cycle changes with time. The middle figure shows how the measured values for the oxygen concentration changes with time at the 75.6 cm station. The bottom figure show how temperature changes with time. Optode drift was investigated for the first 6 cycles.

the same set of instructions were performed repeatedly. With a linear fit giving an R^2 value of 0.86, excluding the last cycle (marked in red). The first cycle, when the lander was emplaced, and the last cycle, when the lander was retrieved, gives largest deviations in cycle time. Figure 13 shows how the change in O_2 concentrations as measured by the optode with time at the 75.6 cm position over the first 6 measurement cycles. The oxygen concentration output does not remain constant for the full 5 minutes (each measurement takes 30 seconds) but no consistent trends can be seen.

Discussion

Operation of lander

The lander was successfully retrieved after operating in the field for 44 hours. High resolution oxygen concentration, temperature, water layer current, and video data was retrieved. However, the motor controlling the elevator was running at retrieval and bottom water samples were not retrieved.

Troubleshooting

The pressure housing protecting the motor had sprung a leak. Water and an unknown opaque substance was found in the pressure housing. An analysis of elevator cycle runtime (see Figure 13, top) shows that the runtime increased throughout the deployment. In addition, the code controlling the elevator contained a bug. A bug that affected the depths at which the elevator stopped. This had the additional effect that the time to perform a measurement cycle increased. Since all measurements waited for the elevator to reach certain positions and to go through these cycles all subsequent commands got delayed. The pump action got so delayed that it did not have time to start before the lander was retrieved. Three separate issues affected the time to perform measurements and together prevented the retrieval of bottom water:

1. The lander was retrieved 2 hours early.
2. The engine housing sprung a leak that impacted the elevator performance.
3. A coding error made all cycles take about 90 seconds longer than calculated.

Any one of these by itself would not have been enough to run exceed the deployment time due to the 4-hour redundancy but taken together they ensured that the lander did not finish its deployment cycle.

The camera

The camera had been tested on land prior to deployment. It was noticed that it didn't fit the housing perfectly. It could move a few millimetres inside the housing. When the footage was analysed it was obvious that the camera had moved a little so that the lens was no longer perfectly aligned with the housing window, thus narrowing the field of view. Furthermore, there is an optical effect due to the relatively higher refraction index of the water that narrows the field of view further which was not accounted for. This can very clearly be seen in Figure 6, in the previous section. The second frame is taken above water and has a markedly larger field of view that the third frame which is taken below water. From the video data, it can be concluded that lander placement contribution to turbidity is negligible within a minute from landing and that it had no impact on subsequent measurements.

Oxygen optode

The optodes were program to measure once per second and give an average of the last 30 seconds every time an output was called for. There was a concern that the optodes would require a larger time than 30 seconds to equilibrate with the seawater after being moved from one depth to the next. That there would be a lag in the output and that the first measurements at each station would carry a signal from the prior station. A small sample of optode data were selected from six subsequent cycles, Figure 13 middle. As can be seen there is variation within each measurement cycle but no clear trend: some increase, some decrease, some exhibit more variable patterns. There are also fluctuations in the measured temperature as evidenced by the lower graph in the same figure. The temperatures are measured by the optodes inbuilt thermistor. On these small timescales the anticorrelation, between oxygen concentration and temperature, that is evident on larger timescales cannot be seen. It is possible that this is an effect caused by averaging 30 seconds of oxygen concentrations but only performing one temperature measurement. Or, that there is a small

lag between thermistor and optode. Furthermore, if there was a lag between measurements at different elevator positions it would be expected that the first measurement at a position would be an intermediate between that of the previous position and the next measurements. No such trend could be seen. It must be acknowledged that the dataset that this conclusion is based on is quite small and not statistically significant. Optode optimisation requires more work in the lab.

The water column

As evidenced by the CTD data, Figure 4, it can be inferred that the whole water column is very well mixed at the time of placement. No halocline nor thermocline can be observed. A small oxygen gradient is visible beginning at 20 meters depth and a marked increase in turbidity is seen at the same depth. Increased turbidity is a common feature of the benthic boundary layer. Turbulence and eddies forming in the BBL can resuspend sediments and keeping sinking flocculates in suspension. Temperature also decrease very slightly at this depth. The bottom water as measured by the optodes is surprisingly homogenous. An oxygen concentration gradient would have been expected since the sediments work as an oxygen sink. There is no marked oxygen concentration gradient with depth not even for the part where the optode was accidentally pushed into the sediment[2]. The oxygen concentrations changes with time seems to be anticorrelated with the temperature for the first 30 (approximately) hours. This would seem to imply that the observed changes in oxygen concentration simply are related to oxygen solubility and that the oxygen concentration was at, or very near, saturation. After that time and forward the oxygen and temperature rather seem to be correlated. In the timeslot 17:53-18:53 (about 28m hours into the deployment) there is a significant[3] decrease in bottom current transport as measured by the ADCP. The water column data from retrieval, Figure 5, exhibit a full water column gradient in all measured characteristics. The fact that there is a full water column gradient, a slowdown in water transport and change in temperature/oxygen patterns at the bottom would indicate that the changes are internal. That the gradients are due to activity in the sediments and/or water column. It is impossible to explain the changes as a whole-water-mass, with fully developed gradients, moving in and replacing the previous water column.

The thickness of the benthic boundary layer is highly dependent on the current velocity, as evidenced by the work of Pope (2000). To be able to adapt the lander to the local conditions then either prior knowledge of those conditions or repeat experiments need to be performed. A further improvement would be increasing deployment time so that data covering a longer timespan can be collected. This would require more work as to optimization of data collection and minimisation of power consumption. The optodes need to be tested more and the reason behind their minute to minute drift must be explored. Is it just changes to the water flowing past or is there more to it?

Conclusions

We see that this benthic lander works and that it can be loaded with a sensor setup providing a wide range of significant high-resolution data. The ease of deployment and adaptability of the loadout enables the lander to be used in a wide range of settings. Most importantly in settings were other methods have significant drawbacks but it can also serve as a complementary to coring or box techniques in any setting. The fact that the measurements are in the water column, providing an integrated view of the total sum of process taking place in the sediments, on the sediment surface, and in the BBL itself gives significant advantages. Together with incubation and oxygen consumption

[2] The optode is of the size of a small fist with a sensor window the size of a nail. It probably left an indentation in the sediments into which the current easily carried water.

[3] The bottom water transport change differs at different water layers. At 3-6 cm, it is a 70% decrease while at 63- 66 cm it is a 30% decrease.

experiments on retrieved cores the oxygen gradient as measured in the BBL can be tied to absolute oxygen fluxes. Which can then be used to normalise and quantify any flux based on a gradient measured in the BBL (Holtappels et al, 2008). This is one of the reasons it is so important to get high-precision high-accuracy oxygen data.

In this short trial experiment the well mixed water column was found to extend all the way down to the surface of the seafloor. By the end of the experiment, 2 days later, a weak full water column gradient was observed. From this limited data set it is not possible to judge whether this is normal for the region. Longer deployment times or several recurrent deployments need to be performed. I also call on this method to be used to quantify leakage of toxins from industrial waste sites or sites where old chemical warfare agents have been dumped. The lander and sensors have been developed to quantify natural processes, mostly related to the nutrients and carbon cycles, taking place in the BBL but can very easily be adapted to different tasks. Increased understanding on toxin concentrations and fluxes would be valuable for decision makers and for all living near or feeding from biomass harvested from affected regions.

Acknowledgements

This project could not have been completed without the guidance and support of my supervisor Volker Brüchert. Julia Steinbach also added valuable input and assistance on all stages of the project.

References

Articles and books

Berg, P., N. Risgaard-Petersen, and S. Rysgaard. 1998. Interpretation of measured concentration profiles in sediment pore water. Limnology and Oceanography 43: 1500-1510.

Boudreau, B. and Jørgensen, B. (2001). The benthic boundary layer. 1st ed. Oxford: Oxford University Press.

Capone, D. G., and E. J. Carpenter. 1982. Nitrogen fixation in the marine environment. Science 217: 1140-1142.

Ekman, V. W. 1905. On the influence of the Earth's rotation on ocean currents. Arch. Math. Astron. Phys., 2, 1-52.

Glud, R. N., J. K. Gundersen, B. B. Jørgensen, N. P. Revsbech, and H. D. Schulz. 1994. Diffusive and Total Oxygen-Uptake of Deep-Sea Sediments in the Eastern SouthAtlantic Ocean - in-Situ and Laboratory Measurements. Deep-Sea Research Part I Oceanographic Research Papers 41: 1767-1788.

Gruber, N. 2004. The dynamics of the marine nitrogen cycle and its influence on atmospheric CO2 variations, p. 97-148. In M. Follows and T. Oguz [eds.], The ocean carbon cycle and climate. NATO ASI Series. Kluwer Academic.

Holtappels, M. et al., 2008. The determination of oxygen and nutrient fluxes in the benthic boundary layer. In ASLO Ocean Science Meeting 2008. Available at: http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-15792.

Jørgensen, B. B. 1982. Mineralization of Organic-Matter in the Sea Bed - the Role of Sulfate Reduction. Nature 296: 643-645.

Mulder, A., A. A. Vandegraaf, L. A. Robertson, and J. G. Kuenen. 1995. Anaerobic Ammonium Oxidation Discovered in a Denitrifying Fluidized-Bed Reactor. FEMS Microbiology Ecology 16: 177-183.

Pope, S. B. 2000. Turbulent Flows. Cambridge University Press.

Redfield, A. C., B. H. Ketchum, and F. A. Richards. 1963. p. 26-77. In M. N. Hill [ed.], The Sea. Interscience.

Schulz, H. D. 2000. Quantification of early Diagenisis: Dissolved Constituents in Marine Pore Water, p. 85-128. In H. D. Schulz and M. Zabel [eds.], Marine Geochemistry. Springer.

Sundby, B., Gobeil, C., Silverberg, N. and Alfonso, M. (1992). The phosphorus cycle in coastal marine sediments. *Limnology and Oceanography*, 37(6), pp.1129-1145.

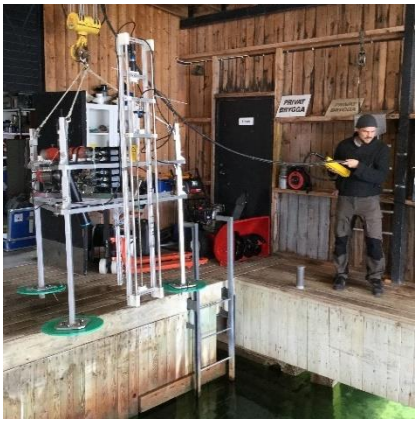
Tengberg, A., De Bovee, F., Hall, P., Berelson, W., Chadwick, D., Ciceri, G., Crassous, P., Devol, A., Emerson, S., Gage, J., Glud, R., Graziottini, F., Gundersen, J., Hammond, D., Helder, W., Hinga, K., Holby, O., Jahnke, R., Khripounoff, A., Lieberman, S., Nuppenau, V., Pfannkuche, O., Reimers, C., Rowe, G., Sahami, A., Sayles, F., Schurter, M., Smallman, D., Wehrli, B. and De Wilde, P. (1995). Benthic chamber and profiling landers in oceanography — A review of design, technical solutions and functioning. *Progress in Oceanography*, 35(3), pp.253-294.

Figures

Figure 1: Boudreau, B. and Jørgensen, B. (2001). The benthic boundary layer. 1st ed. Oxford: Oxford University Press.

Appendix

The User's Manual, below.



ASSEMBLING, RUNNING, AND MAINTAINING A SEA-FLOOR LANDER AND ITS EQUIPMENT: PROFILING THE BENTHIC BOUNDARY LAYER.

A users Guide

Table of figures

Introduction

The benthic boundary layer (BBL) is the water layer closest to the seafloor which is directly influenced by the water-sediment interface and water sediment interactions. This layer generally exhibits strong oxygen and nutrient gradients due to the activities of microbes in the sediments. In addition, shear due to water layers moving relative to the sediments and to each other give rise to increased turbulence and eddies that can resuspend sediments and keep sinking particles in suspension. This combination of high number of suspended particles, available oxygen, and nutrient leakage from the sediments below makes this a very dynamic region

A benthic lander loaded with measuring devices provides a way to perform non-invasive in situ measurements of this dynamic region. This has the added benefit that measurements can be performed in regions were normal coring techniques fail, such as very sandy sediments or mussel banks. It is also easy to change the instrument loadout making this a versatile platform for various scientific investigations.

Overview

The purpose of this document is to make it easy to assemble and operate a certain benthic lander with a given component setup. The lander which has a carefully chosen set of instruments for data collection on both the seafloor and the part of the water column which is situated just above the seafloor, the BBL. The intent is that by reading this manual you should get a basic grasp on the functions of the various instruments as well as how to assemble and operate the lander.

The printed version of this manual was supplied with a USB stick. On this USB stick are all pertaining software that the lander requires. A copy of this manual is also there. It is recommended that this manual is continually updated and that any changes should be noted under the Updates chapter of the manual.

What the manual is

This manual will serve as an instruction in how to assemble, calibrate, and operate a benthic lander. It will serve as a brief introduction to the instruments. The theory behind how they function, their parametric characteristics, and to serve as a step-by-step guide on how to get the lander in good working order. The manual will also be a manual in the basics in how to operate the software that controls the instruments.

What the manual isn´t

This manual will and cannot cover everything related to the instruments. For in depth information and troubleshooting consult the factory manual for the respective instrument.

How to read the manual

The manual will generally start with a brief overview of the instrument. This is to provide you with basic information of how the instrument works. Then it will discuss how to connect the instrument followed by how to use the software that controls the device. To make it easier to read a certain format was chosen:

- When a program requires you to use a specific **Command**, then it will be written in **this format**.
- *Very specific information as to specific settings as well as information that could be considered " working experience" or "good advice" will be given in italics.*

- If you are to look for a certain output signal or follow a certain pathway it will be given in **this format**.

  *E.g. To find out which USB devices are connected to your computer follow these instruction: Open **Sök i Windows**. Type **kontrollpanelen.** From **Kontrollpanelen->System och säkerhet->System->Enhetshanteraren**[4]**.** Then find **USB-styrenheter** in the list.*

Software and example code

The instruments require numerous programs to communicate with each other, to perform calibrations, to collect data, and for post processing. In addition, all these programs are supplied separate on a USB stick. On this USB device are copies of all the manufacturers manuals. A pdf copy of this manual will also be on the USB stick.

[4] An equivalent way of doing this would be by just searching for **Device Manager** directly.

Equipment and assembly information

The lander is composed of a tripodal aluminium framework. The aluminium frames are treated to be corrosion resistant and allow for various components to be attached easily. This makes it easy to change, replace, and add parts. One such part is a motor with a separate movable frame – an elevator– which we in turn can add or remove sensors from.

A number of different components and sensors can easily be attached to the lander frame. Several of these are controlled and monitored by a central steering and logging device, while others are autonomous.

The centrally steered interconnected components are:

- Battery
- Steering device and logger
- Oxygen optodes
- Peristaltic pump
- Motor with movable frame

The autonomous components are:

- Aquadopp HR current profiler
- Digital camera
- LED light

The fully assembled lander will look something like this:

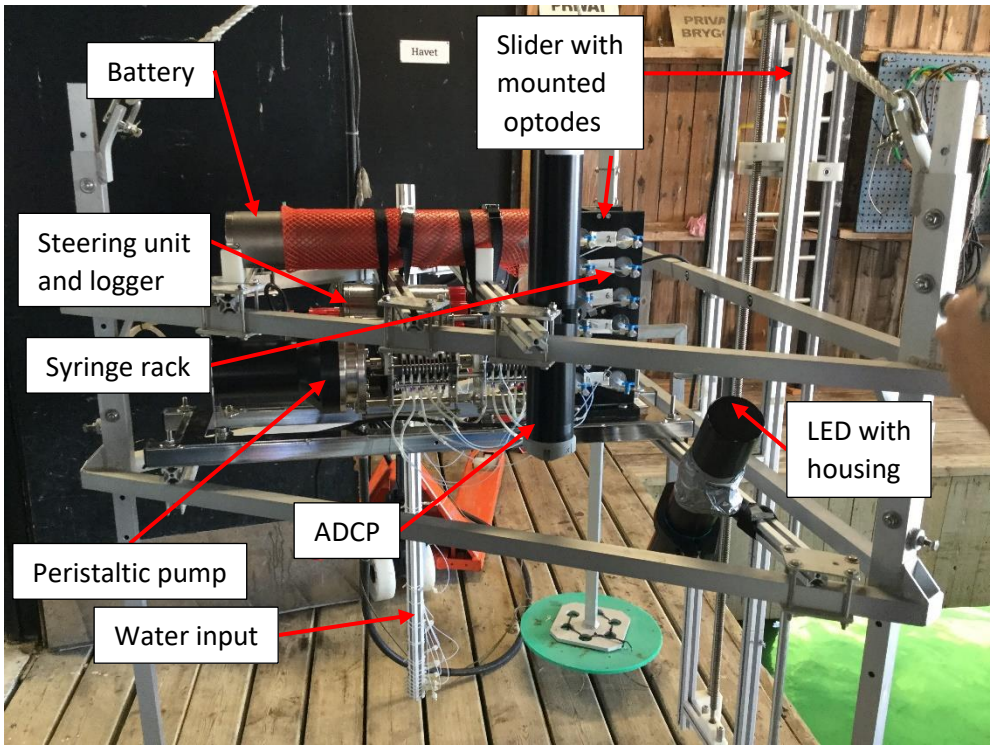


Figure 14: A fully equipped benthic lander.

The steering device and its connected components: What goes where

The battery (Figure 15) via the battery cable (Figure 17) connects to the steering device (Figure 16).

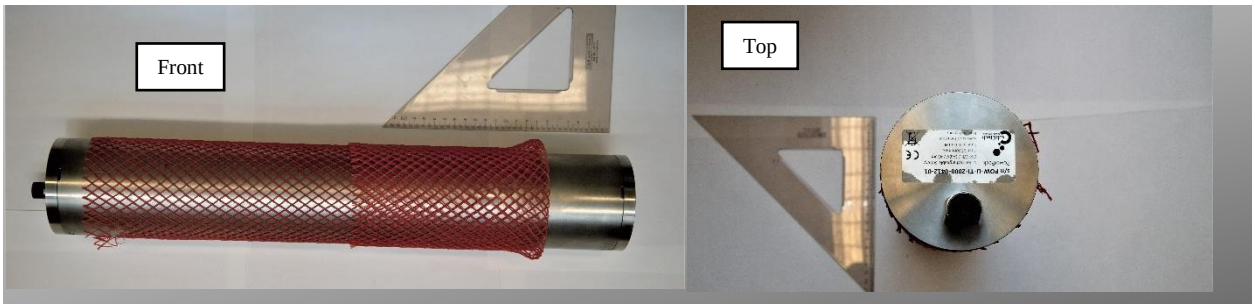


Figure 15: Battery with a 5-pin(f) connection.

The steering device (Figure 16) distributes current from the battery to the connected devices, i.e. the optodes, the motor, and the pump; controls how they run; and logs runtime and measurement data collected from these devices.

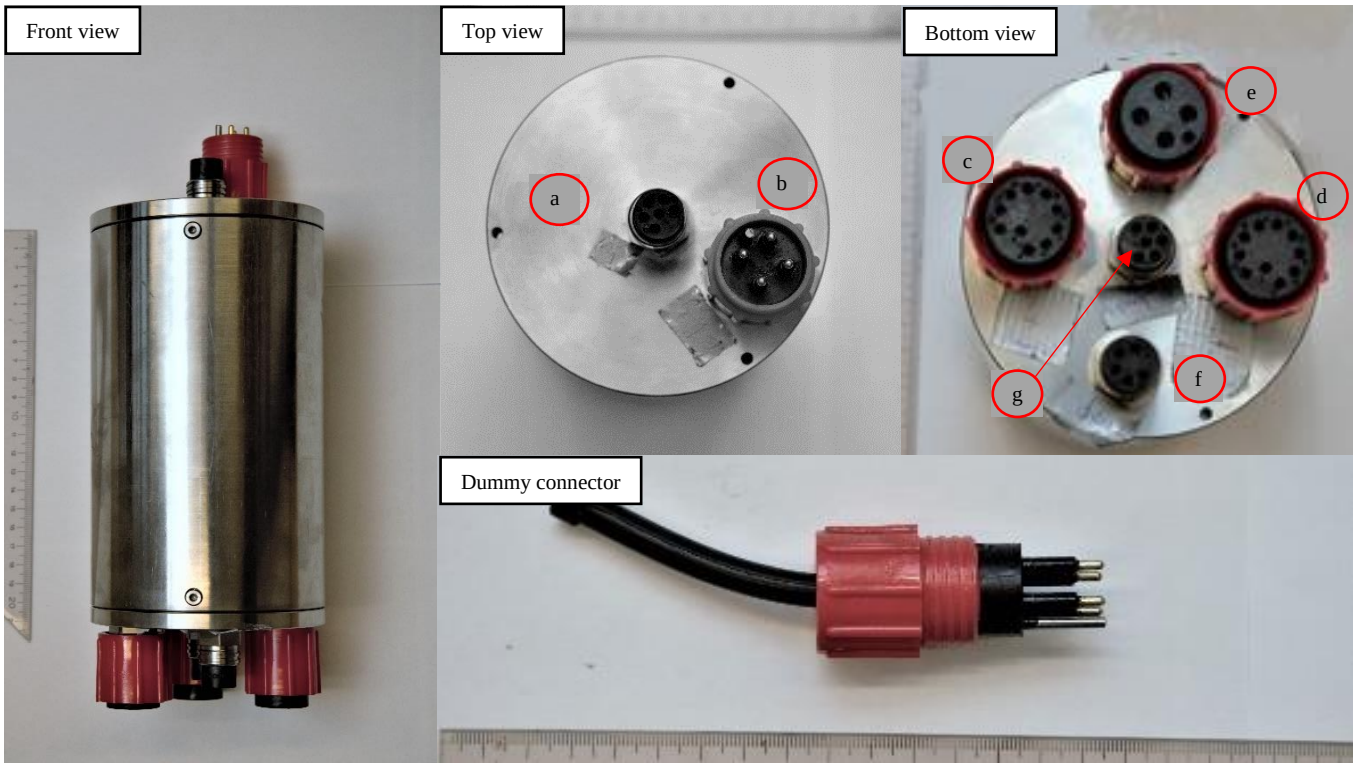


Figure 16: Logger and steering device.

The steering device has seven outlets with variable number of pins depending on what is to be connected to it. The outlets are for: Top view a) 6-pin outlet for PC connector b) 5-pin connector for the battery cable; bottom view c-d) oxygen optode 10-pin connector e) dummy f) pump 5-pin connector, and g) engine 6-pin connector. Dummy connectors are to protect the outlets which aren't in use. The various cables that we use are shown below (Figure 17).

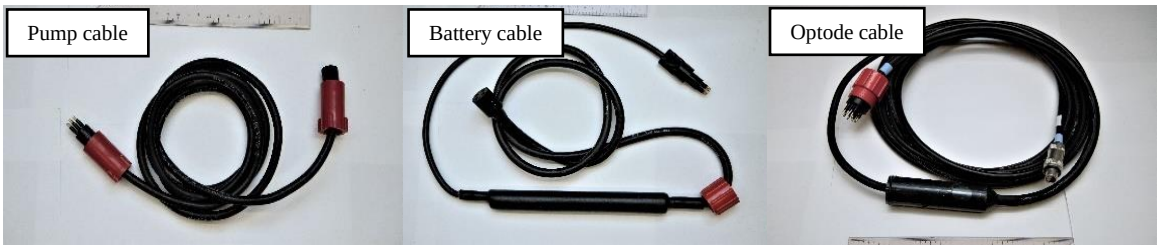


Figure 17: Cables. Pump cable, battery cable, and optode-to-logger 10-pin connector cable 3485 (x2).

The cables are: pump cable, battery cable, and optode-to-logger 10-pin connector cable 3485 of which there are two. The optodes (Figure 18) are connected to the steering device using the optode cable (Figure 17, right). Two optodes can be connected at any one time and the optode cables are marked with red and plastic stripes to distinguish them from one another.

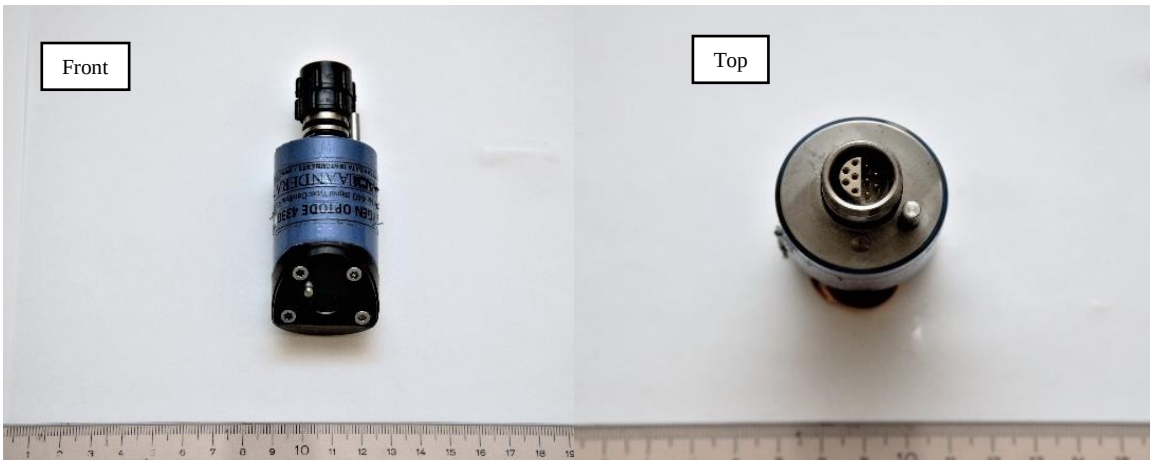


Figure 18: Aanderaa oxygen optode 4330. With a 10-pin screw coupling.

The peristaltic pump used for water sampling is also connected to the steering device. The pump pushes water through a series of hoses to syringes, which are set in a rack. The syringes are used to store and easily retrieve the water samples. The hoses that run through the peristaltic pump are made of silicone and the hoses leading to the inlets and the syringes are Teflon hoses.

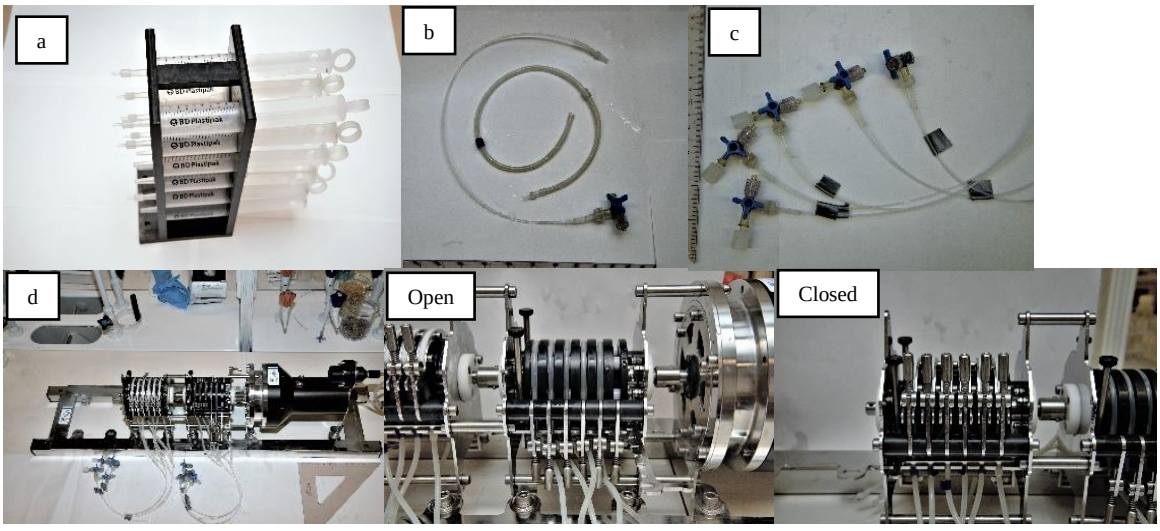


Figure 19: Peristaltic pump with hoses. a) rack with syringes, b) 3 x 5 mm silicone hoses to loop through the peristaltic pump, c) 3-way stopcocks to connect the hoses to the syringes, d) Peristaltic pump, e) hose housing open, f) hose housing closed.

Figure 20:Motor with frame and cabling. The frame is approximately two meters high

A 2-m frame with a small movable section, an "elevator" can be attached to the lander. The elevator is driven by a motor that rotates a threaded rod. The threaded rod runs through a connector that allows for the small elevator to move in the vertical, see Figure 21 left. To this elevator sensors, such as the optodes, can be attached. Other autonomous devices such CDTs and similar could also be attached.

Autonomous components

The autonomous components in the current setup are: a camera with pressure housing, a current profiler, and a LED with a pressure housing. They all run on their own, internal, power supply and they all store data internally. The ADCP and its accessories can be seen in the top of Figure 22, with the ADCP head shown zoomed in. The camera, the camera housing and the LED with its housing are shown in the bottom of said figure.

Figure 21: Autonomous components. Top: ADCP. Bottom: Camera (a), camera housing (b)-(c), and LED with housing.

The battery

Subsea Li-Ion PowerPack

Li-Ion Technology 14.8V / 45Ah / 666Wh

- **The battery pack can be customized.**
- **Use two packs to double the capacity or voltage**
- **No need to open the housing! Charge under water.**

Specification		
Technology	Li-Ion rechargeable battery with high-power, high safety, highly reliable cells and BMS	
Applications	Subsea Instrumentation, Long-time deployments & Monitoring, ROV/AUV Power	
Housing	Titanium Ø 90 mm, Length 530mm, customizing on request	
Weight	7.9 kg 4,5 kg 22 kg	at air (Standard 2000m version) in sea water Complete with Cargo Flight-case 720 x 420 x 220mm (LxWxH)
Connector	MCBH-5F	SubConn® Micro connector ● other on request
Operating depth	Standard 2000m, deep-sea version 4000m and 6000m	
Temperature	-20 ... +60 °C 0 ... +40 °C -20 ... +50 °C	Operating temperature Charge temperature Storage temperature, best +5 .. +15°C
Voltage	14.8 V 12.0 V 10.0 V	Open voltage Minimum voltage Minimum voltage for full lifetime and performance
Capacity	45 Ah 41 Ah	Rated capacity, +20°C, after 50 cycles Typical capacity, 0°C, after 100 cycles
Current	7 A	max. continuous current, other up to 40A on request
Self discharge	20 %	per year at +25°C, 10% per year at 0°C
Charge cycles	>800 cycles	for 80% remaining capacity
Protection	17.4 V over-charge, 9 V under voltage discharge, 9 A current limiting after 1s	
Charger	*SmartCharger*™, can be connected all time. Do not open the housing for charging. Special procedure to revive deeply discharged batteries. Signal LEDs for Power, Charging, 100%, Error. IP65 protected for on-board usage.	
Switch	Optionally remote switch for ROV or Diver operation	
Special supply	Optionally special power supplies with DC/DC	
Transportation	The battery must be transported as dangerous goods class 9. SubCtech is registered as a vendor of batteries. Transported by sea, air or road. We are pleased to advise you.	
Storage	Storage at +5 .. +15°C. medium-full charged. Recharge after 4-8 weeks. We provide storage/transport boxes with low-power cooling devices and charging.	

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Figure 22: Battery pack.

The Aanderaa oxygen optode 4330

What is an optode?

An oxygen optode is an optical device for measuring oxygen concentrations. It operates on the principle of dynamic luminescence quenching. Which is the ability of certain molecules to affect the fluorescence of other molecules. In this case oxygen (the quencher) is interacting with and quenching the fluorescence of the platinum porphyrin (the flourescer) in the detector foil.

An inbuilt diode sends out light and excites an electron in the platinum porphyrin molecule, putting it in a higher energy state. Normally the platinum porphyrin would deexcite and re-emit light which can subsequently be detected. However, in the presence of a quencher (in this case oxygen) the platinum porphyrin can also de-excite by transferring the energy to a colliding quencher-molecule. The intensity of the re-emitted light is thus inversely proportional to the concentration of quencher molecules. Measuring absolute intensity is a bit tricky so the detector actually works by comparing the phase change of the re-emitted light – the presence of the quencher affects the decay time of the excited state – to the phase of a reference LED.

Since this is an optical device incoming light can interfere with the detector. Therefore the sapphire window that protects the foil is painted black. Scratches to the black paint could allow light, from the sun or from fluorescent particles in the water, into the detector thus introducing an error into your measurements. In Figure 23 you have a cross-section of the optode and the optode specifications. The sensor has an integrated thermistor that is uses to automatically linearize the phase measurements.

> *The accuracy is usually better than that specified below. In close to anoxic conditions an precision of 100 nM is to be expected while at oxygen saturation an precision of around 700 nM is more likely.*

The sensor can be set to adjust for salinity, or salinity can be compensated for during post processing. This is because the sensor measures the oxygen saturation (partial pressure) and not the absolute concentrations. The oxygen concentrations are calculated from the saturation which is affected by the salinity. Pressure also affects the accuracy of the measurements and must be compensated for during post processing.

> *If the measurements are performed where the salinity undergoes significant changes then the salinity should be measured separately and compensated for during post processing. If the salinity variation is only minor, less than 1 ppt, then specifying and using the internal salinity setting is good enough.*

The optodes should preferentially be supplied with 5 V. If supplied with a higher voltage the electronics will make sure that the detector itself is supplied with 5 V but having a higher voltage supply will induce some self-heating in the electronics. Since these electronics are situated away from the thermistor the optode cannot correct for it when it linearizes the phase measurements. If the sensor is set to do more than one sample every 5 s then the error introduced *can*[5] be as high as 1-2 µM. The optodes can output the measurements in µM or in oxygen saturation. Temperature output is in ºC.

Post-processing

The sensor foil that houses the platinum porphyrin is only permeable to gas and not to water. Thus, it measures as if immersed into fresh water. The salinity of the water can be compensated for internally by the optode by programming it with the salinity for which the measurements were conducted. If salinity changes higher than 1 ppt are to be expected during a run then salinity should be measured separately and compensated for during post-processing. The detector foil response is pressure dependent and the pressure the optodes experience will also affect the measurements. Depth (pressure) must be compensated for during post-processing.

[5] Allegedly. We see much smaller variations when we test this in the lab.

Compensating for salinity

If the sensor salinity was set to zero and the measurements were conducted at a higher salinity then the oxygen concentrations must be compensated for afterwards using the relationship:

$$O_{2c} = [O_2]e^{S(B_0+B_1T_S+B_2T_S^2+B_3T_S^3)+C_0S^2}$$

Where $[O_2]$ is the measured oxygen concentration, S is the measured salinity in ppt[6], T_s is the scaled temperature which in turn is given by

$$T_s = ln\left[\frac{298.15 - T}{273.15 + T}\right]$$

where T is the temperature in °C. The other constants are experimentally determined and given by B_0 = -6.24097x10^{-3}; C_0 = -3.11680x10^{-7}; B_1 = -6.93498x10^{-3}; B_2 = -6.90358x10^{-3}; and B_3 = -4.29155x10^{-3}. If the salinity settings of the sensors are not zero but also <u>not</u> that of the surrounding water then that can be compensated for by using:

$$O_{2c} = [O_2]e^{(S-S_0)(B_0+B_1T_S+B_2T_S^2+B_3T_S^3)+C_0(S^2-S_0^2)}$$

where S_0 is the internal salinity setting of the sensor (in ppt). All other parameters are as given above.

Compensating for pressure

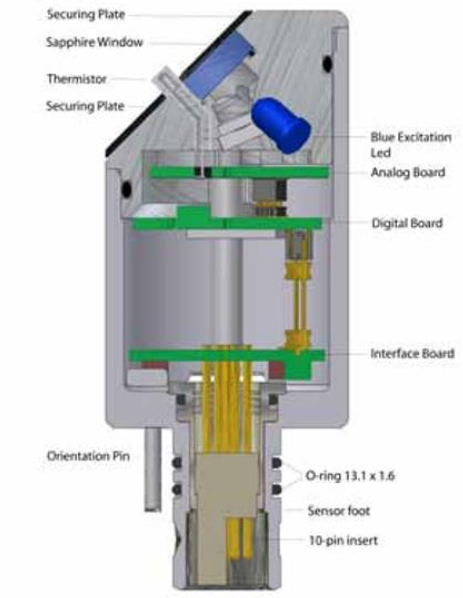
During post processing, you must also compensate for depth.

$$[O_{2c}] = [O_2]\left(1 + \frac{0.032d}{1000}\right)$$

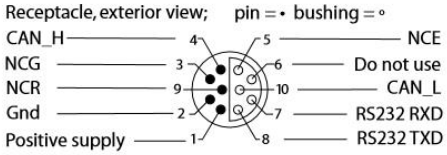
where $[O_{2c}]$ is the depth compensated oxygen concentration, $[O_2]$ the measured oxygen concentration, and d is the depth (m). So, we must compensate the measured $[O_2]$ by 3.2% for each 1000 m of depth.

[6] It is assumed that there is negligible difference between ppt and the values given using PSS.

Optode specifications



PIN CONFIGURATION
Receptacle, exterior view; pin = • bushing = ◦



OXYGEN:	**O_2-Concentration**	**Air Saturation**
Measurement Range:	0 – 500 µM [1]	0 - 150%
Resolution:	< 1 µM	0.4 %
Accuracy:	<8 µM or 5% [2] whichever is greater	<5 % [3]
Response Time (63%):	4330F (with fast response foil) <8 sec 4330 (with standard foil) <25 sec	
TEMPERATURE:		
Range:	-5 to +40°C (23 - 104°F)	
Resolution:	0.01°C (0.018°F)	
Accuracy:	±0.1°C (0.18°F) [4]	
Response Time (63%):	<2 sec	
OUTPUT FORMAT:	AiCaP CANbus, RS232	
SAMPLING INTERVAL:	2s – 255 minutes	
SUPPLY VOLTAGE:	5 to 14Vdc	
CURRENT DRAIN:		
Average:	0.16 +48mA/S where S is sampling interval in seconds	
Maximum:	100mA	
Quiescent:	0.16mA	
OPERATING DEPTH:	0 – 6000 meters (0 – 19690ft)	
ELEC. CONNECTION:	10-pin receptacle mating plug CSP	
DIMENSIONS (WxDxH):	Ø36 x 86mm (Ø1.4"x 3.4")	
WEIGHT:	280g (9.88oz)	
MATERIALS:	Epoxy coated titanium, PA	
ACCESSORIES (not included):	Set-up and config Cable 3855[5]/3855A[5] Standard Foil Service Kit 4733 PSt Fast Response Foil Service Kit 4794 AiCap extension cable with CSP 4793 CSP to free end cable 4762 CSP to PC cable 4865 Patch Cable 3969492	

[1] O_2 concentration in µM = µmol/l. To obtain mg/l, divide by 31.25
[2] requires salinity compensation for salinity variation < 1 psu
[3] within calibrated range 0 - 120%
[4] within calibrated range 0 - 36°C
[5] for laboratory use

Figure 23: The Aanderaa optode. Specification sheet taken from the Aanderaa optode manual.

Optode maintenance

The optode requires minimal maintenance. It can operate and collect high quality data even when heavily bio-contaminated. However, if it is bio-contaminated then consumption and production of oxygen by the bio-contaminator may cause the sensor to return the oxygen concentration at the biofilm and not that of the water. Also, if the sensor foil is heavily fouled then the response time of the sensor may go down as it will take longer time for the oxygen to diffuse. If the fouling is caused by calcareous organisms then a weak acid can and may be used to dissolve them.

The manufacturer claims that their experience is that the calibration last for several seasons. However, they recommended that a recalibration is performed once a year.

Prior to attaching the cables make sure the connector pins are clean and apply a small layer of a silicone lubricant e.g. 3M™ Silicone Spray. Also make sure that the O-rings are clean and in good working condition. Use a small dab of silicone grease to lubricate them. Damaged O-rings must be replaced. For damage on the optode foil or the foil cover, see the manufacturers manual. The 10-pin connector cable that connect the optode to the steering device need two different O-rings on the optode connector part. The large one is an O-ring Angus RM 0096-24 (9.6 x 2.4 mm) and the thin O-ring is a 10 x 1 mm Simrit Materiale15.

The calibration procedure is quite simple and easy to perform so it could be performed before every deployment. That is, ***if*** *you are feeling paranoid.*

The sensor should work well even if the black protective layer is scratched or damaged but it will be more susceptible to sensor foil bleaching and may be more sensitive to the presence of ambient light or fluorescent particles that might interfere with the measurements.

If the sensor foil is severely damaged then it may have to be replaced. A new foil can be bought from Aanderaa.no and new foil coefficients must be entered into the optode. How to perform this procedure is dealt with in the optode user manual, chapter 5.1.

Calibrating the Aanderaa Optodes

The optode can be calibrated from a PC by connecting the optode directly to the PC via optode sensor cable 3855 and using a terminal emulation program to communicate. Communication should be done via the RS232 protocol. The sensor cable can be connected via a serial port or an USB port, if the serial to USB converter is used (Figure 24, below). The optodes have an internal flash memory that stores the settings and configurations. The different configurations and settings are write protected with different access levels (See table 1-2 on page 10 of the operating manual for details).

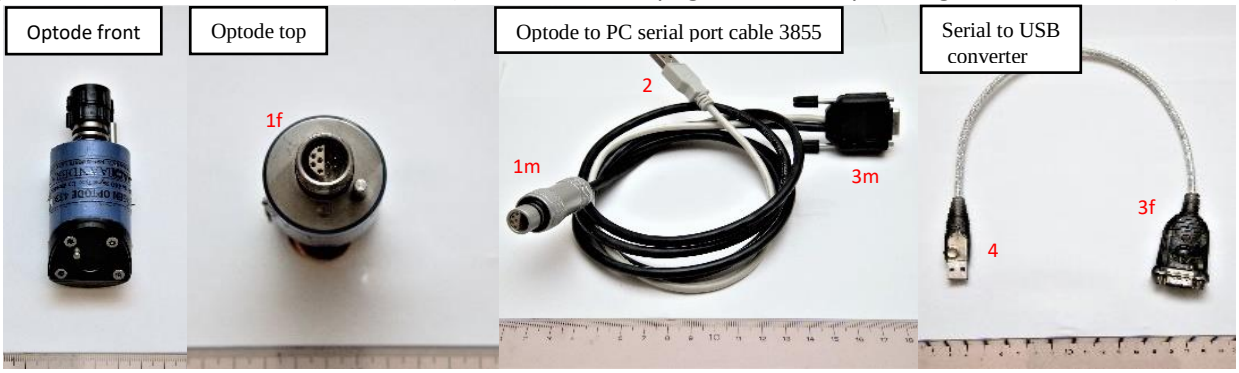


Figure 24: Aanderaa optode, sensor cable 3855, and a serial to USB converter. The sensor cable allows for communication between the optode and a PC. 1) f connects to m, 2) connects to a USB port and supplies the optode with a current, 3) 3m connects to a PC serial port or to 3f if a USB conversion is needed 4) connects to a PC USB port.

Before you start

Prior to starting the calibration procedure, it is important to ensure that the detector foil on the optodes are thoroughly wet. If there is reason to suspect that the foil may be dry, then the detector must be submersed in water at least 24 hours prior to calibration. The optodes can perform measurements while dry and when held in the air but the measurements are not perfectly reliable. Attempting to calibrate the optodes with a dry detector foil can introduce a measurement bias of up to 2%. Also, ensure that the O-rings on the sensor cable are in good working condition and free from grime and dirt. Damaged O-rings must be replaced to avoid potential damage to the optode circuitry. Read through the next section of this document fully before starting.

Equipment needed

- Two 500 ml beakers with milli-Q water that is in temperature equilibrium with the room in which the calibration is to be performed.
- 10 g of sodium sulfite (Na_2SO_3).
- A PC with a terminal emulation programmed of your choice installed.
- Sensor Cable 3855. Possibly together with serial-to-USB cable depending on the sockets of your computer.
- Optodes

Calibration procedure

The optodes can be connected directly to a PC. Communication with the optodes are performed using a terminal emulation program. Through this emulator, codes can be written directly to the optodes flash memory or prewritten in .txt format and uploaded to the optodes. The optodes will be calibrated using two calibration points. The first from water that is 100% saturated with oxygen and the second from water that is totally anoxic. The calibration procedure is as following:

1. Prepare two 500 ml beakers with milli-Q water. Make sure that the water is in temperature equilibrium with the surroundings. This could take hours if the milli-Q water is freshly prepared or taken from a room with a different temperature.
2. Connect an aquarium pump to one of the beakers and pump air through the water. This will ensure that the water is 100% oxygenated. The water in this beaker will be used for the 100%-saturated calibration point.
3. Connect the optode to a PC using a Sensor Cable 3855 (see Figure 25)The optodes can be connected directly to a PC serial port or to an USB port if a Serial-to-USB adapter is used. The USB connector can be either attached to a computer USB-port or to the USB-port of an external power supply. This supplies the optode with its working voltage. The watertight plug is to be connected to the optode.

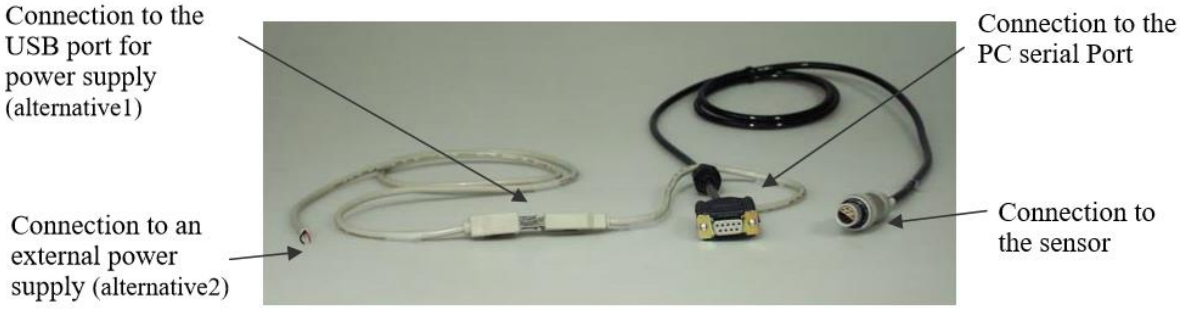


Figure 25:Sensor cable 3855 with connection information.

4. Start your terminal emulation program of choice. As mentioned earlier the communication is using the RS232 protocol and the following settings should be used for the terminal emulation program settings:
    - 9600 Baud
    - 8 Data bits
    - 1 stop bit
    - No parity
    - Xon/Xoff Flow Control

      Furthermore, in the settings for the emulator program make sure that **Local Echo, Send line ends with line feeds,** and **Echo line ends with line feeds** are all enabled.

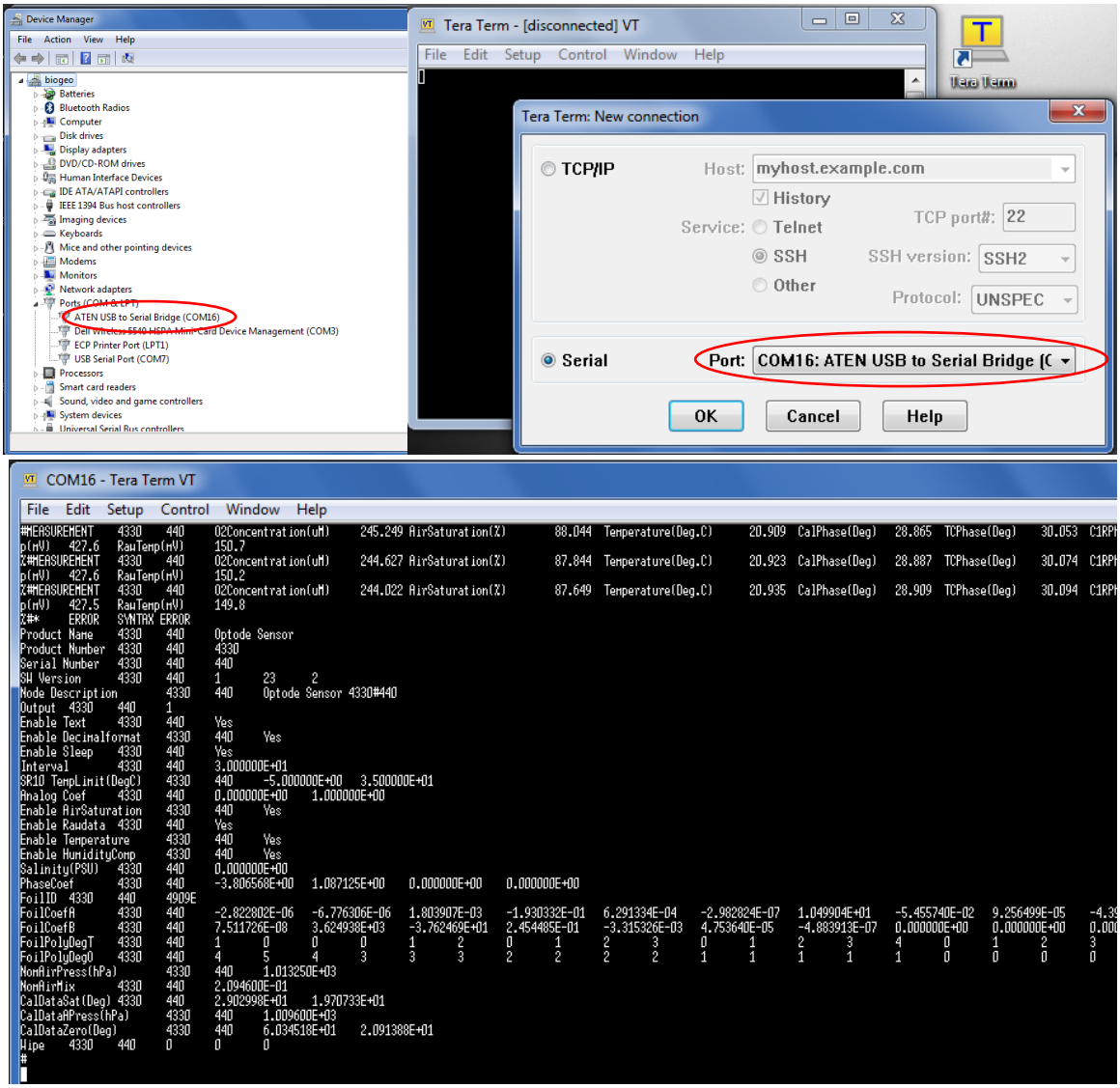


Figure 26: Connecting the optode using Tera Term.

5. You should start receiving measurements from the optode straight away. The optodes will send its data according to what it was previously programmed to do. This interval can be changed using the **Set Interval** command. The flash memory on the optode has several layers of write protection. Prior to changing any setting a command to disable the write protection must be sent. This is done using the **Set Passkey** command. When a setting has been changed, it must be saved. The example code on the left disables the write protection, sets the measuring interval to every 30 seconds, and saves these settings. If the optode prints its outputs on the screen when you are trying to input commands, then that will interrupt that command. A measurement interval of 30 seconds gives you time to input your commands while still collecting data at a good pace allowing for a good overview of the stability of the output.

Defines the optodes measuring interval. Setting it to 30 seconds.
Set Passkey(1) Set Interval(30) Save

6. Turn off the aquarium pump and wait a few minutes. Then lower the optode into the water. Make sure that there at no time are any air bubbles on the foil window. Air bubbles will interfere with the measurements. The reason for waiting is that the action of the aquarium pump can supersaturate the water and when you wait you give time for any small air bubbles

to effervesce. If the optode had been in the water during this time these air bubbles may also form on the optode foil. This would introduce a bias in the measured O_2 concentration.

7. Monitor the **Temperature(Deg. C)**, the **CalPhase(Deg)**, and the **TCPhase(Deg)** output. When these outputs are stable (usually within a couple of minutes), you are ready to start the calibration.

Collect and save calibration data for the oxygenated calibration point.
Set PassKey(1) Do CollectCalDataSat

8. Start by disabling the write protection followed by the command to collect the calibration data. No separate save command need to be entered at this time.
9. Put 5 gram of Na_2SO_3 in the second beaker. The sodium sulfite will react according to:

$$2Na_2SO_3(s) + O_2 \rightarrow 2Na_2SO_4(aq)$$

thus scrubbing oxygen from the water. If you can see sodium sulfite crystal on the bottom of the beaker it is safe to assume that the water is anoxic. Should all sodium sulfite be dissolved you can simply take out the optode, pour in some more, wait a bit, and then proceed as before.

10. Remove the optode from the first beaker, rinse it in milli-Q, and gently wipe the optode clean. Now insert the optode into the second beaker and let it rest. Once more monitor the output until the **Temperature(Deg. C)**, the **CalPhase(Deg)**, and the **TCPhase(Deg)** outputs are stable.

Collect and save calibration data for the anoxic water
Set Passkey(1) Do CollectCalDatazero

11. To collect data for the second calibration point input these commands. As before, no separate save command is necessary.

Specifies the air pressure used in the calibration
Set PassKey(1000) Set CalDataAPress() Save

12. When we have both calibration points we have to specify the air pressure for which the data was collected. This is done using the **Set CalDataAPress()** command. The air pressure should be entered in between the brackets and given in hPa.
*Note: you need to enter a higher level command to disable the write protection for the **Set CalDataApress()** and that you need to enter a separate **Save** command afterwards.*

Perform the calibration
Set PassKey(1) Do Calibrate

13. Finally, we tell the optode to perform the calibration with the **Do Calibrate** command. It should now be calibrated and ready to run.

Notes and comments of the procedure

- The optode commands works even if you do not capitalise the various commands[7].
- **Set passkey(1)** allows for disabling of low level protection. **Set Passkey(1000)** allows to change all values including optode coefficients. Do not use needlessly.
- Make certain that there at no time are any gas bubbles on the optode foil window even small bubbles will interfere with the calibration.
- If you have changed and saved any settings you have to restart the sensor for the new settings to take effect. This can be done by turning of the power or by the **Reset** command.

[7] I´ve kept the capitalisation since I think it makes the commands slightly easier to read.

- The **Get All** command prints all the settings for the optode. Can be good to check when you change settings just to make sure that the new settings were saved properly.
- **Do Start** and **Do Stop** tells the optode to start respectively stop measuring.
- Commands can also be prewritten in a text editor and sent to the optode using a send text file option in the terminal emulator.

A list of all commands is given in table 4-2 on page 25 of the TD 269 OPERATING MANUAL – OXYGEN OPTODE 4330,4835 found on the USB stick.

The peristaltic pump

The pump is a peristaltic pump supplied by KC Denmark. It works on the principle of compressing the hose containing the liquid and displacing the trapped liquid by rotary action. This means that the liquid is in no time in contact with the pump itself just the hose through which it is conveyed. The hoses that run through the pump are connected to a series of syringes on one end and to an inlet with a filter on the other end. These inlets are in turn attached to an aluminium bar and can be adjusted to be at different heights above the seafloor.

Technical information

The pump is a 12-channel system, that is it operates 12 pumps at the same time. With each channel being able to be opened or closed independently. The pump can operate on 10-24 Volt DC. A higher voltage makes the pump work faster. The voltage supplied by our battery will generally provide 14-15 V. The pump is modular and modules with additional 3 or 6 channels can be attached. The motor is pressure compensated down to a depth of 6000 m. The hoses that runs through the peristaltic pump should have an inner diameter of 1.5 to 3.0 mm and have a thickness of 0.5 mm. The volume/time that the pump pumps depends on the voltage it is supplied with and the inner diameter of the hose. If the pump revolves with 10 rpms and has a hosing with an outer diameter of 4 mm and an inner diameter of 3 mm then it should pump approximately 14 ml/min. The hose that runs through the pump is made of silicone and the hoses that connect to the syringes and to the water inlet are made of Teflon®.

Installation

We have a rack with 12 syringes (Figure 27 a) that through a 3-way stopcock connects to a Teflon® hose which in turn connects to a silicone hose (Figure 27 b). This soft pliable hose is pulled through the peristaltic pump and fastened so that it is tight. A clamp folds down over the hose and presses it against the rotating rollers that give rise to the peristalsis. How hard these clamps press down can be adjusted by a small screw with an Allen key[8] fitting (too small to see in the figure). The silicone hose is then again connected to a Teflon® hose which, finally, connects to an aluminium bar where the

[8] Also known as an hex key, IKEA key, or sexkantsnyckel.

inlets are fixed at different heights (Figure 27 d). Here one-use filters, to minimise the risk of biofouling in the hoses and syringes, (orange) are attached at the very end.

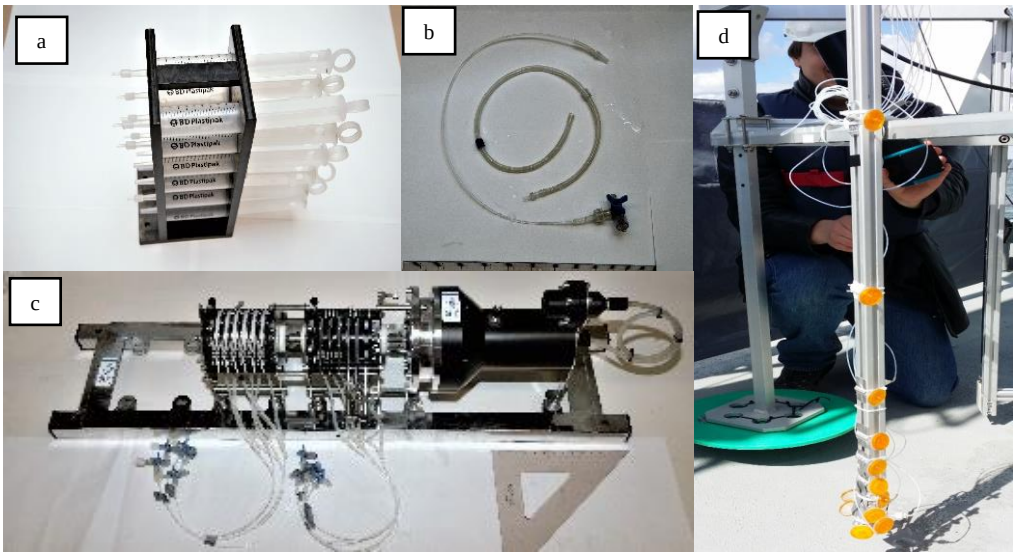


Figure 27: Peristaltic pump, syringes, hosing, and fitting for the outlets.

The motor with frame

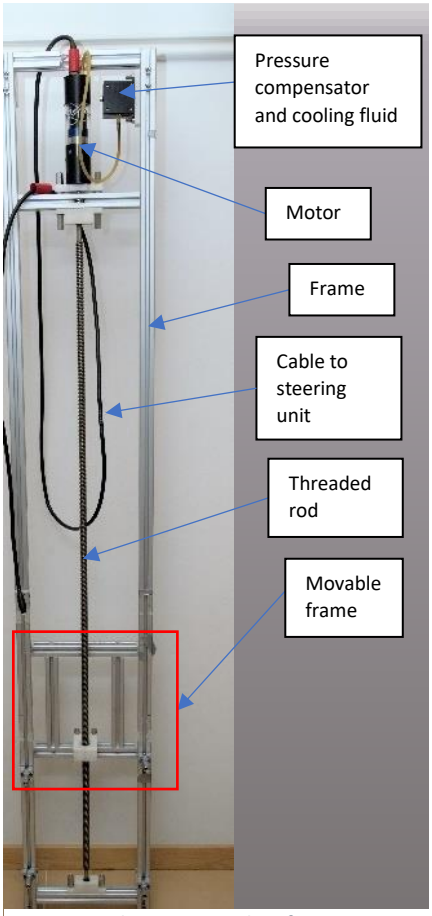


Figure 28: The motor and its frame.

The motor is attached to the top of a 2m long frame. Through a coupling the engine turns a threaded rod to which another, movable, frame is attached. By rotating the rod the secondary frame moves up or down. The distance it moves is directly related to the revolutions of the threaded rod and allows for a high precision in distance moved. The movements of the engine are fully programmable using the software for the steering device.

The engine is set in a pressure housing and connected to a pressure compensator. The fluid in the pressure house is Flourinert which is an electrically insulating cooling fluid. It should be made sure that the Flourinert fully fills the pressure housing. Air in the housing would be compressed at depth setting up a pressure gradient with the outside. The pressure housing itself is just a polycarbonate cylinder and it cannot withstand any greater pressure differences. Thus, trapped air imposes a risk of water leaking in potentially short circuiting the engine.

The rod is not threaded at either end. This is so that the movable frame cannot forced out of bounds which could cause damage to the frame, the engine, or the connection of the engine and the threaded rod. The movable frame moves 18.94 mm per 10.000 motor units, as programmed in the steering device. Moving the engine in the “positive direction” moves the frame downwards.

The Logger and Steering Device

The steering device distributes the voltage from the battery to the devices connected to it. It also communicates with the motor, the detectors, and the pump and is controlling how and when the various components are switched on and how they operate. It can also store data collected by the sensors. However, it deletes all data every time new commands are uploaded.

USB Nano

The USB Nano connects directly to a PC USB port on one end and to the steering device on the other. It converts from the RS-232 standard of the steering device to the Universal Serial Bus (USB) standard at the computer. USB nano drivers are supplied on the USB stick that comes with the manual. The drivers can also be downloaded and installed directly from the manufacturers website. If the computer is connected to the internet then Windows should try to download and install the drivers automatically.

Potential problems with the USB Nano

The USB nano chip has software that is incompatible with windows versions newer than Windows 7. So, the USB Nano can only be used on a computer that is running Windows XP – Windows 7. Trying to use it on a newer machine is futile. New software for the USB nano chipset can be bought (3.5 euro) and downloaded from the manufacturers website. The installation of new chipset software must be installed from a windows XP – 7 device. However, it is not clear if the updated chipset software is backwards compatible.

Communicating with and programming the steering device

The software we use to communicate with the steering device was developed by Paul Färber of MPI in Bremen. The software is written in C++ but all the commands can be accessed using classical windows HUD. Alternatively, the code can be written and read in a .txt format. The software that are used to communicate with the steering device allows you to: open communication through specified ports; create scripts for the actions that you want the steering device to perform; and to upload those scripts and to download data stored in the steering device. It consists of Mpibuscomserver V1_1.exe, MPIBusEditor V1_09.exe, and MPIBusLoggerDownload V1_16.exe.

> *References to the names of these programs are[9] hardcoded in their respective C++ code and they could stop working properly should the names be changed. Thus, they should not be changed.*

Mpibuscomserver V1_1.exe

Tells the computer how to communicate with the steering device, its IP address, which ports to use etc. This program must be run first to establish communication with the steering device. A way to find out the com-port is by using windows search feature, **Sök i Windows**. Search directly for

[9] Allegedly.

Enhetshanteraren. In the menu on the left find **Ports (Com & LPT)**. The com port number will be listed here. This com port is then used as in Figure 29, below.

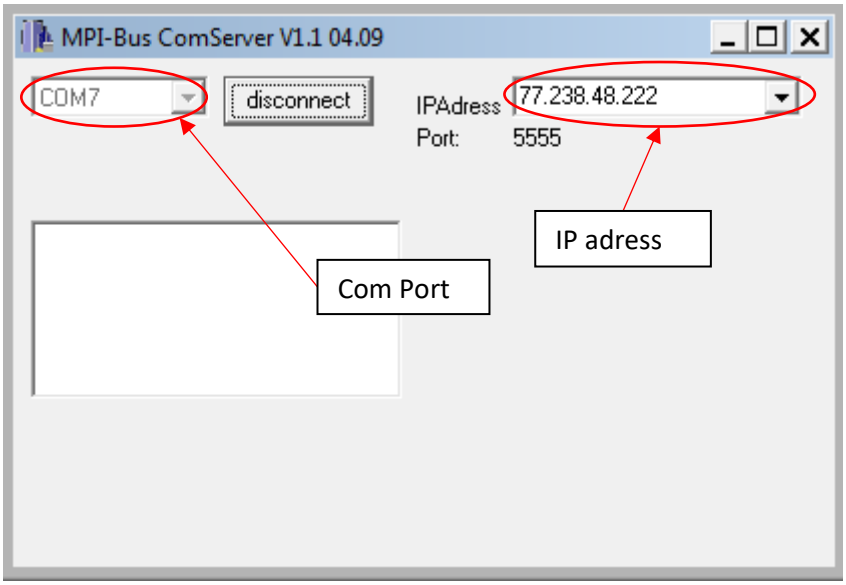


Figure 29: MPI-Bus ComServer. Correct com port must be chosen. The IP address shown is the one needed for the MPIBusLoggerDownload program.

> *If you make a mistake and chose the wrong port the program will seem to work. However, you will not be able to upload any programs or communicate with the steering device in any way. A quick way to test for this is by trying to upload a program through MPIBusLoggerdownload with a **Logger: Get Status** command. If you have chosen the wrong port or if the USB Nano is glitching then you will be able to tell immediately. However, uploading a new program will wipe the memory of the steering device. For how to upload programs to the logger, see next section.*

MPIBusEditor V1_09.exe

This is a program for creating scripts to run the various instruments connected to the steering device. The steering device can only read and understand hex-files. These can either be created manually using a text editor and a code in the hex-format or, more easily, using the MPIBusEditor. This program contains pre-defined commands for the set of instruments used with the lander that can be arranged to programs, as well as a tool to convert the programs (saved in text format) to the hex-format accepted by the steering device.

The MPIBusEditor is controlled by MPIBusDevices.MPIdev which can be read and edited using a normal .txt editor, e.g. notepad. This file controls what is what is shown in the MPIBus Edit v 1.09 window and defines how they are to communicate with the steering device as well as what kind of commands they can receive from the steering device. This MPIdev file can be updated, within reason, if the detector setup were to change. However, how to do that is beyond the scope of this manual[10]. The MPIBusEdit window is as in Figure 30, below. There you can see the list of the devices as defined in the MPIdev file. From this window, you can open further windows for creating or editing scripts that controls the steering device and hence all instruments attached to the steering

[10] We used it to make the output list match the current sensor setup by editing out legacy sensors.

device. Main programs will be stored with an .mpilg extension and subprograms are stored with an .mpilsr extension.

1. Opens a new window for creating steering scripts. Whether this script will be the main program or a sub-routine is decided by the format on which it is saved, i.e. mpilg, for the main program, or mpilsr, for a subprogram.
2. Opens an already created steering script file.
3. Converts an already created script file from txt-format to hex-format (.mpihex) . The hex-format is what the steering device can understand and read.
4. Closes the window.

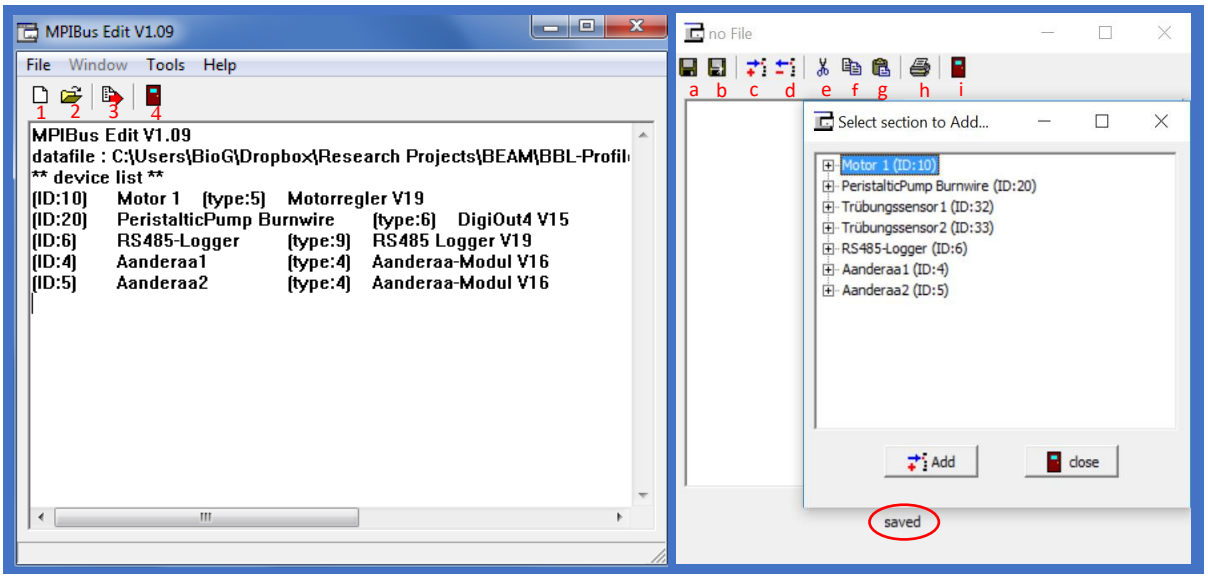


*Figure 30: MPIBusEdit window with sub windows. In the left window 1) **Open**s a new window (hindermost window to the right), 2) **Open**s already saved steering file (like the hindermost right window but with whatever commands it contained), 3) Converts a saved .mpilpg file to hex (.mpihex) format, and 4) **Close**s the program. For the window on the right, a) **Save** the file, b) **Save as**, c) Open window with commands (foremost right window), d) **Delete** added command, e) **Delete** added command, f) **Copy** command line to clipboard, g) **Paste** command line, h) **Print**, and i) **Close** window.*

The list of possible commands can be expanded and all possible commands can be seen in Figure 31, below. How they work will be further expanded on in the next section and an example of how a more complex code looks and how these various commands interact will be in the section after that.

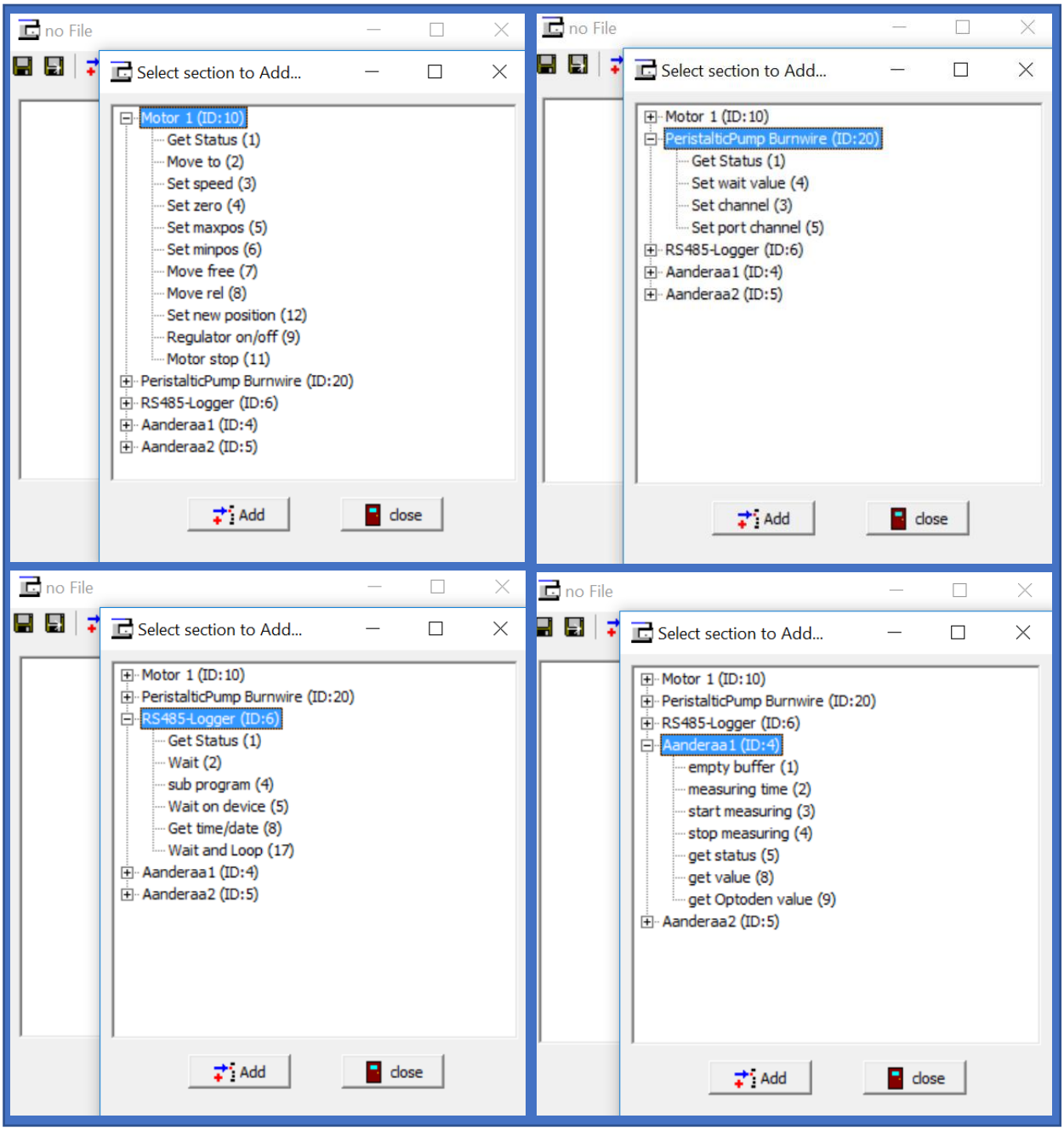


Figure 31: Steering device commands. These are the possible commands that the steering device can be coded to perform.

Motor commands

Table 4: Commands governing the motor that moves the movable frame.

Command	Description	Possible choices
Get Status	Prints engine status in the output file.	---
Move to	Moves to a location.	-2.1e+9 - +2.1e+9
Set speed	Determines the rotational speed of the motor.	0-255 (0-33, drains ~1.5 V, 70 ~ 3 V, 150 ~ 7 V, and 255 ~ 12 V)
Set zero	Determines the zero-location.	---
Set maxpos and **Set minpos**	Sets the interval for which the motor may run[11].	-2.1e+9 - +2.1e+9
Move free	Moves the engine until it reaches the threshold or it runs out of time. Should be used with a **Wait** command.	1. Motor on positive 2. Motor on negative 3. Watch for threshold (given by Set max/min-pos)
Move rel	Moves a distance relative to the current position.	-2.1e+9 - +2.1e+9
Set new position[12]	Defines current position to have a value.	-2.1e+9 - +2.1e+9
Regulator on/off		0-65535
Motor stop	Turns the engine off.	---

Pump commands

Table 5: Commands controlling the peristaltic pump.

Command	Description	Possible choices
Get Status	Prints pump status in the output file.	---
Set wait value	???	???
Set channel		1-8
Set port channel	Which channel to turn on/off. 1 is on, 0 is off.	Channel: 1-4 On/off: 0/1

Logger commands

Table 6: Logger specific commands.

Command	Description	Possible choices
Get Status	Prints logger status in the runtime output file.	---
Wait	Waits for this amount of time before executing the next command.	0-65535 seconds

[11] Remember that the motor will be attached to a threaded rod and that a revolution of the engine will correspond to a distance. This command ensures that you can program an interval for which the engine are allowed to raise or lower the attached frame.

[12] This is usually used to define a zero point. To which you can return with the **Move to** command.

Sub program[13]	Links to a subprogram. You can command it to repeat the sub program by specifying the number of loops.	Link to a MPIIsr file. Number of times you want to run this subprogram, 0-65535.
Wait on device	Waits until a chosen device is no longer active.	
Get time/date	Prints time and date in both output files.	---
Wait and loop	Not quite sure. Have not tested extensively.	0-65535 loops

Aanderaa optode commands

Table 7: Optode commands.

Command	Description	Possible choices
empty buffer	Empties flash memory	---
measuring time	Defines the period for which to average measurements.	
start measuring	Starts measuring. A delay before may be entered	Delay: 0-65535 seconds.
stop measuring	Turns the optode off. Can be used to save energy.	---
get status	Prints the optode status in the runtime output file.	---
get value	Prints optode name, O_2 concentration, and temperature in the output data file.	
get Optoden value	Prints chosen value in the runtime output file.	Channel: 1-8

[13] If loop=0 is used as the last command then it will loop this infinite amount of times. Does not work to edit out a sub program.

Example Code

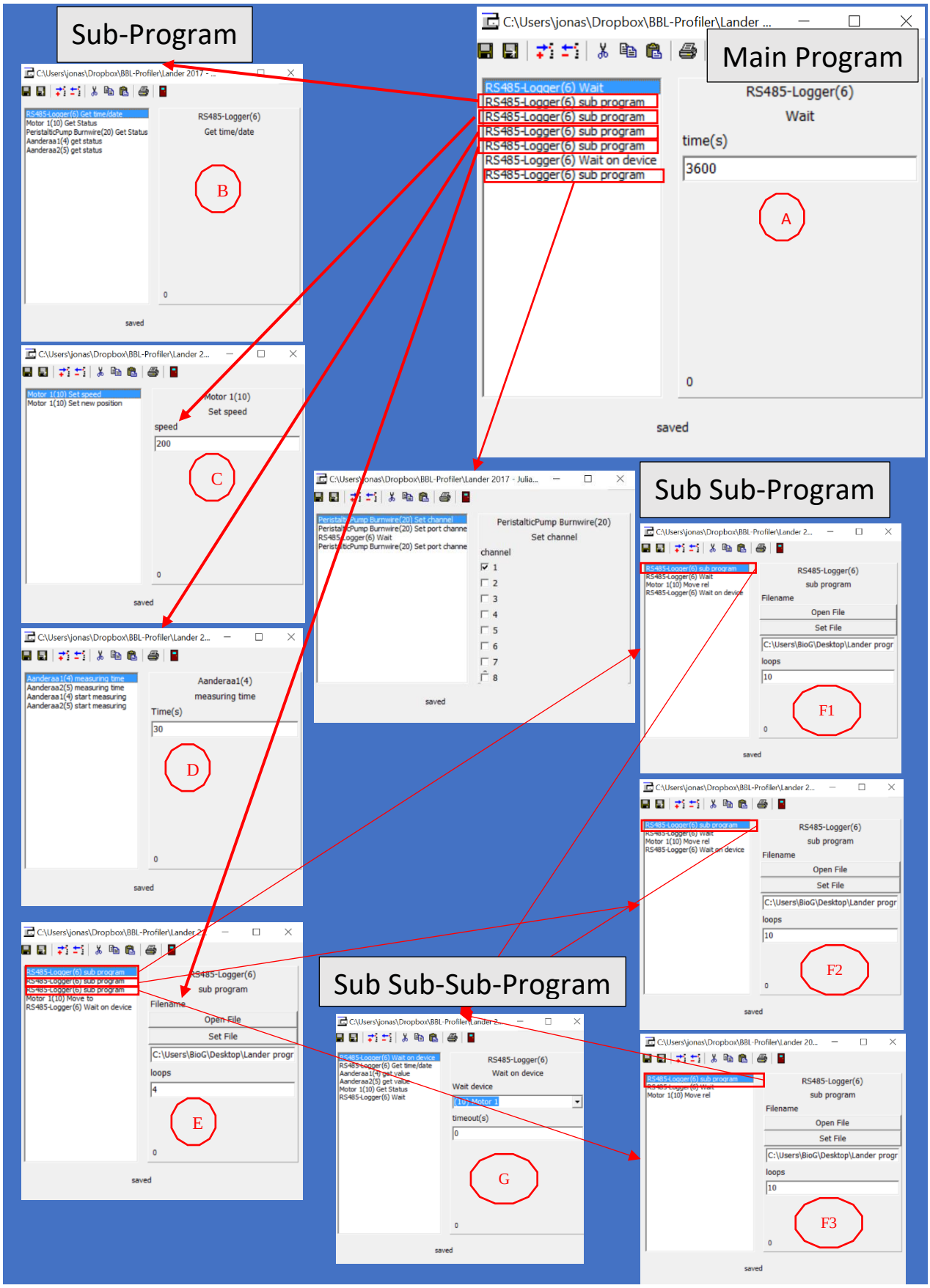


Figure 32: Showing how to structure a flexible program for running all 5 connected components.

In Figure 32 we see an example of how you can structure the code to achieve high flexibility, easily edited and changed, and a level of conciseness. The main program (A) Starts with a **wait** command. This specifies how long the program should wait from the start of the program until it should go to the next command. In this example it has been coded to wait for 3600 seconds which provides more than ample time to emplace the lander and for any disturbed sediments to settle. Next in line is a **sub program** which points to (B). This sub program prints the time/date and the status of all the engine, the pump, and the optodes in the output file. This is just so that it is easier to troubleshoot in case a component fails to execute its command later on. Next in line is sub program (C) which defines the motor speed, via **set speed**, and the current position to be the zero position, via **set new position**, for the elevator. Next sub program, (D), to start defines the **measuring time** for both optodes and tells them to **start measuring**. One could build in commands to turn them off during motor movement to save energy but that is not done in this code example. Now in (E) it is time to start the elevator engine and start recording data. Notice that we have three sub programs in this sub program. That is so that we easily can move the engine different intervals and take measurements. F1-F3 all point to the same sub program (G). (G) controls the data collection. It tells the logger to **wait on device** (engine) so that we don't accidently take measurements while the elevator is moving. Then in turn: **Get Time/date**, **get value** (optode 1 and 2), **Get status** from the motor, and move the engine different amounts and **wait**[14] 1 second. Notice the order. If the command order is wrong i.e. not in the same order as that as defined by MPIBusDevices, you will still get an output but the layout will be messed up. These commands will prompt an output with date, time, optode measurements, and where (in engine units) the elevator is. (F1-F3) loops 10 times and since we had in (D) defined the measurement time to be 30s each stop takes 5 minutes and 10 seconds. The number of loops we give sub program (F1-F3) in (E) will define how many times it will move and measure for each defined motor movement. The last two lines in (E) tells the elevator to return to origo and then tells the program to wait until it the elevator has returned there by the **wait on device** (engine) command before proceeding. This is one measurement loop. In (A) we can define how many times the subprogram (E) should repeat this. Finally, the last sub program in (A) tells the pump to start (**set channel**, **set port channel** (1)), run for an amount of time (**wait**), and then turn off (**set port channel** (0)). The channel used in **set port channel** should, obviously, be the same as the one defined in **set channel**.

This code was used to: get status output; define motor origo position; define speed; define how the optodes measure; take measurements at 100, 80, 60, 40 60, 20, 16, 12, 8, 7, 6, 5, 4 ,3, 2, 1, and 0 centimetres above the sediment surface. Repeat this cycle 33 times then start the pump and run the pump for 13[15] minutes. Changes to how the elevator moves, how many measurement cycles are run how long and how many times a measurement are taken at a given position are all easily changed by changing a single number each.

[14] This command is most likely superfluous.

[15] 13 minutes was chosen since this was the time it takes to fill a syringe from 10 ml to 100 ml during a test run. A test run during which the peristaltic pump worked perfectly.

MPIBusLoggerDownload V1_16.exe

Obs, requires that Mpibuscomserver is running in the background!

This program is used to upload code and to download data from the steering device.

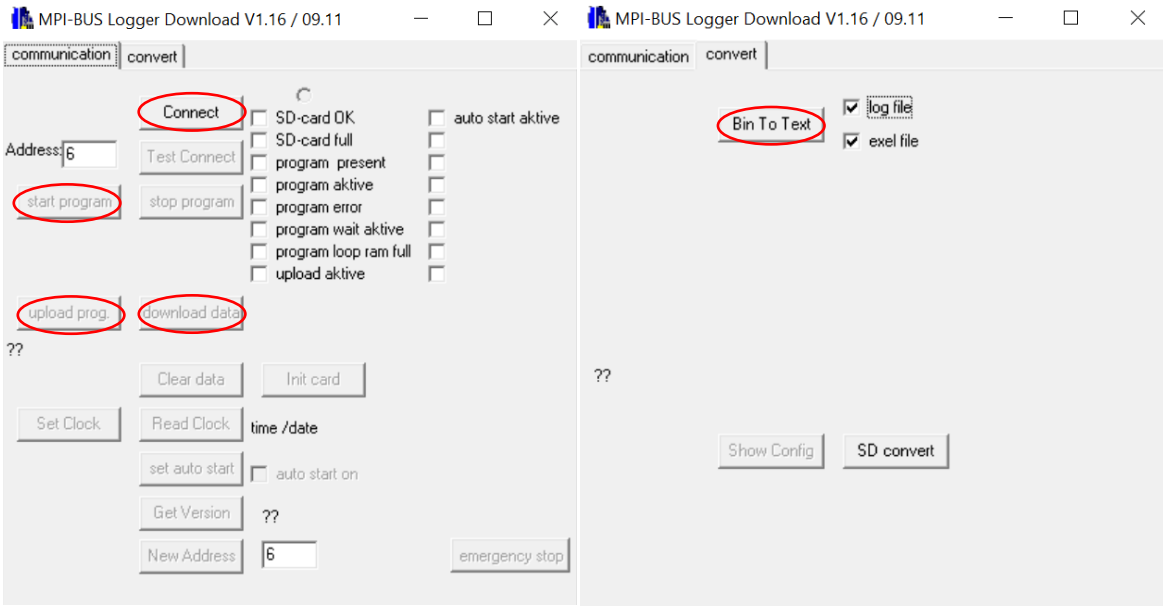


Figure 33: MPI-BUS Logger Download. This program is used to upload programs, start and stop programs, and to download and convert data to and from the steering device.

First, you need to **Connect** to the steering unit. Then you can upload your hex file with commands using the **upload prog.**. Uploading new instructions deletes the previous instructions as well as all data stored. A pop up window will ask you if you are *Really* certain. Make sure that you really are sure that you want to perform this step. When this is done, you can **start program**. Now the steering program will perform whatever you have told it to do. After the program has run its course, or if you stop it prematurely[16], then you can **download data.** Data stored on the device is stored in binary format to save space. Pressing **convert** changes tab and there you can choose if you want the data the log file, a text file with data, or both. After choosing **Bin to Text** finishes the procedure.

> *When you download new data give it an new unique filename. It is possible to use and overwrite an existing name but when you try to convert the data from .bin to .txt then it will try to create new .txt files with the original name and cannot at this stage overwrite an already existing text file.*
>
> *I recommend using the current setup on an old machine and to buy a newer USB nano if you want to control the steering unit from a more modern computer.*

[16] Sometimes **stop program** does not work and you will have to use the **emergency stop**. For some reason this seems to most often happen when the pump is running.

Aquadopp HR-profiler

Aquadopp HR current profiler, 2 MHz, measures current speed and direction in multiple layers of the water column. The high resolution (HR) models measures within ranges of a few cm. Operates on the principle of the Doppler effect. The transducer head sends out a pulse and then measures the frequency shift of the reflected sound. This it converts back into velocities. The emitted pulse reflects on various particles suspended in the water, e.g. zooplankton, air bubbles or similar. In extremely clear water it may be needed to seed the water with particles to act as reflectors (this will never be a problem in the Baltic Sea). The assumption being that these particles that reflect the sound wave are free-floating and moves with the same velocity as the surrounding water. Since the detector measures phase shifts, and calculates velocity from those, we run into the problem of velocity ambiguities at phase shifts outside ranges of ±π. You can set up the instrument to minimize this risk by setting a Nominal Velocity Range (which is the highest velocity you are expected to encounter) in the Deployment Planning. Velocity ambiguity usually shows itself as an abrupt change in velocity and also usually with a sign change. Shorter lags between pulses allows for higher maximum velocities but, conversely, longer lags generally have lower noise levels. The transducer that sends out the pulse is also used to measure the reflected pulse. But since the transducer vibration take some time to die down (it essentially rings, like a bell) there is a time window where it cannot measure. So, it cannot receive measurement too close to the detector. Too close in this regard is around 10 cm.

The Aquadopp contains a compass system that measures the magnetic field in three dimensions and an instrument to measure tilt. Battery packs and mounting disturbs the local magnetic field and the compass needs to be calibrated in association with deployment (See ADCP manual p. 102). The ADCP measures pitch roll and heading once every second. It can be programmed to use different coordinates: it can measure in “beam”-coordinates, Cartesian or ENU (East-North-Up, since it has a tilt and an inbuilt compass, see p. 111). ENU is too be preferred since that is a system that isn´t relative to deployment directions. The ADCP must be mounted vertically to ensure quality data. The device cannot measure too close to device nor to close to the seabed due to sidelobe interference. Rmax = A cos(θ) – Cell size. Page 115, see also page 103.

Mounting Guideline and Deployment Configuration

The ADCP should be positioned so that it is pointed directly downwards. If it is mounted slanted then it will still be able to perform measurements but the data quality will suffer and both precision and accuracy will be lost when post processing calculations to compensate for this are performed[17]. If possible it should also be positioned so that there is no beam interference from the lander itself. It will measure pitch, roll, and heading once every second. The device can be program to use “beam” coordinates, cartesian or compass coordinates from the inbuilt compass. Since we will very little control of which direction the lander will be facing it is probably best to use the compass coordinates, East-North-Up (ENU).

When the AquaDopp profiler is in place a recalibration of its internal compass must be made since the metals of the lander and the various components can interfere with it. This is a very simple procedure that takes about a minute.

1. Install the AquaDopp on the frame with all other equipment. Make sure the frame is horizontal and that the AquaDopp is mounted perfectly vertical.
2. Connect it to a PC using the cables shown in Figure 22 and start Aquapro HR.
3. **Communication -> Serial port** and choose the correct port. You can also specify a baud rate.

[17] Page 113 in the manual goes over this in more depth.

4. **Communication -> Connect**.
5. Click **On-line** then chose **Compass Calibration** and follow the instructions.

Since the frame needs to be rotated during the compass calibration this is most easily performed if the whole frame and all components are hanging by its ropes.

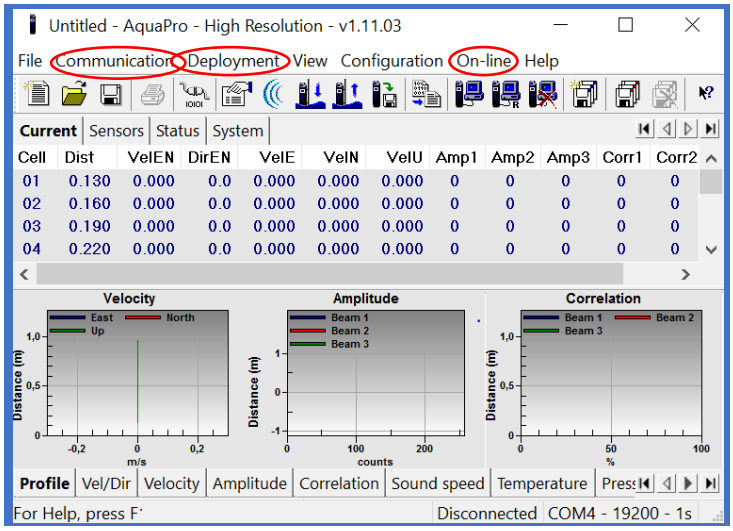


Figure 34:AquaPro Hr. The program to communicate with the AquaDopp current profiler.

Before deployment you need to specify what and how you want to measure. This is performed in the **Deployment -> Planning**. Here you can specify quite precisely how it is mounted, how many layers you want to measure, and under what conditions. It is also possible to load and reuse settings. Then in **Deployment -> Start Recorder Deployment…** you can specify when you want it to start recording.

When you retrieve AquaDopp post deployment you need to:

1. Turn it off. **Deployment -> Stop Recorder Deployment**.
2. Download data. **Deployment -> Recorder Data Retrieval…** This step can take a substantial amount of time. It collects a lot of data each second. It is recommended that you the option to divide the file into smaller chunks is used.
3. Convert the data to files you can read. **Deployment -> Data Conversion…**

The data set retrieved will be very large and trawling the data to clean up artefacts, noise and just in general ensure that it is of good quality is quite a task. It is recommended that Nortek's SeaReport software is used at this stage. It can be leased from Nortek for a fee of 800 NOK per week. This will most likely save both time and money in the long run.

The camera, the LED, and their pressure housing

LED

You can program the led chipset so that the LED turns on and off according to simple cyclical patterns. It has 4 control lights that indicate which parameter is active (see Figure 35). The parameters are, from top to bottom: MD, T1, T2, and NX. MD controls the mode, T1 and T2 are time units ranging from 0-9999, and NX, depending on which mode you are using, controls how many cycles it should run or how the time parameters T1 and T2 are calculated .

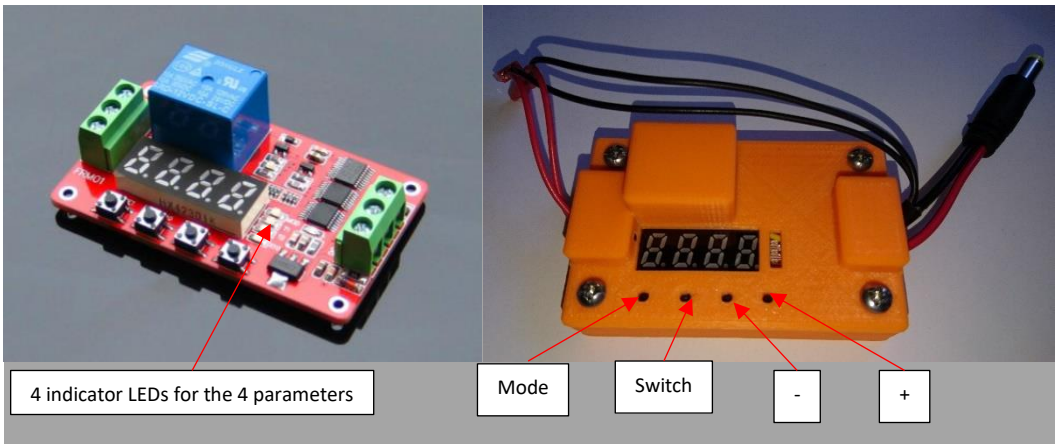


Figure 35: Led control chip FRM01. Open (left) and with its cover (right).

Hold and press **Mode** to enter edit mode. In edit mode you can press **Mode** to change between MD (0-18), T1 (0-9999), T2 (0-9999), and NX. Use the **Switch** button to move from right to left between which number you want to edit, and use (**+**) and (**-**) to raise or lower that number. When you are finished once more press and hold **Mode** to exit edit mode.

> *A simple program that serves our purpose is to have Md = 8, T1 = 3600, T2 = 1800, and NX = 30. This example would have the light turn on at once when the battery is connected, wait 3600 s and then turn the lights off, wait again 1800 s then turn the lights on again. And repeat this cycle 30 times.*

For the other modes and more advanced use please see the user manual – Timer Relay Module (FRM01) User Manual – supplied on the USB.

Camera

The camera is a waterproof GoPro 5 camera. It has a video mode, photo mode, and a time lapse mode. The special camera housing is cut from a block of solid aluminium and is certified to work down to a depth of 2600 m. But the General Purpose Housing (GPH) that is used as an extender for batteries and control chips are only certified down to 1750 m. As it is, there are no fancy ways of programming the camera. It will have to be started manually and then be allowed to run until the memory card is full or the batteries are depleted.

If the camera is run using 30 fps and 360p resolution then the battery will last for 2 hours. An empty memory chip will be able to store 6 hours' worth of video using these settings.

Pressure Housing

The pressure housing for the LED and the camera is supplied by GroupBinc in Florida. The general Pressure housing is certified to work down to 1750 m depth.

Add small silica bags inside the housing prior to deployment to soak up any condensation that might form which could damage the wires or occlude the camera lens.

Make sure to tighten the housings firmly. If you open the housing for the square camera lens make sure that you don't overtighten the screws when you put the lid back on. Overtightening them may damage the anodizing of the screws and since the screws and housing are of different materials damaged screws may led to corrosion via electrolysis.

Post deployment the housing should be rinsed in warm water, soaked in lukewarm water, dried and inspected. It is important that the O-rings are not damaged. If there is the merest hint of a suspicion that they are damaged then they should be replaced.

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Updates and version

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