Module Test reports

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Part A: ICASP Module Test Report

1 Introduction

In the period between 2012 and 2013 ICASP was deployed during several expeditions along with the AUV of the Alfred Wegener Institute (AWI). The cruise HE 377 (RV Heincke) in April 2012 and the two arctic expeditions ARK 27/2 (RV Polarstern, July 2012) and MSM 29 (RV Maria S. Merian, June / July 2013) are to be mentioned specifically. At the beginning of 2012, the payload of AWI´s AUV was expanded with a nitrate sensor whose data are stored on ICASP´s core unit, the PCC.

The specific operating conditions and maneuver of the AWI-AUV entailed a modified post processing of the measurement data. For this reason new software tools were developed in winter 2012 / 2013.

2 Progress in data quality

Since the beginning of 2012, the AUV team of the AWI uses a special maneuver to analyze the layers of the upper water column. Using this so called “Float”-maneuver, the vehicle is sent to a specific location and deactivates its thruster as it reaches this position. Due to its residual buoyancy the vehicle starts a slow ascent towards the surface and records a vertical cast of the water column.
The sensors of ICASP are distributed along the AUV´s payload section which is located at the very front end of the vehicle. As the vehicle freely floats in the water it occupies an orientation according to its center of gravity. Thus, depending on the pitch and roll angle, each sensor will be in an individual depth. ICASP does not have own depth sensors but the measurement data are synchronized with the vehicle´s navigation data. As one cannot assume the depth sensor of the respective carrier vehicle to be in the proximity of ICASP, the spatial orientation of the vehicle was integrated into data post processing.
The depth error due to pitching and rolling of the vehicle can be compensated by exactly determining the position of ICASP´s sensors with respect to the depth sensor of the vehicle. The vectors derived from these measurements can be rotated using rotation matrices like given in Equation 1. The roll and pitch angels of the vehicle are entered into these matrices and the vectors are rotated into the “real” position at the respective time.
Figure 1 shows the axes and angles used in this calculation.

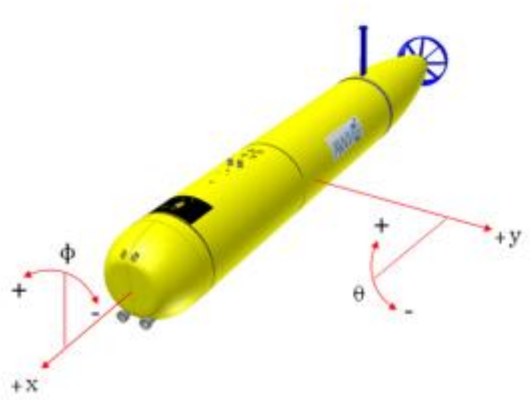

Figure 1: Orientation of axes and angles used for data correction

In the matrix, n_x, n_y, n_z represent the Cartesian components of the unit vector of the rotation axis $\vec{n}$.

$$R_{\vec{n}}(\alpha) = \begin{pmatrix} n_x^2 t + r & n_x n_y t - n_z s & n_x n_z t + n_y s \\ n_x n_y t + n_z s & n_y^2 t + r & n_y n_z t - n_x s \\ n_x n_z t - n_y s & n_y n_z t + n_x s & n_z^2 t + r \end{pmatrix}$$

With α being the angle of the respective rotation, the variables *r*, *s* and *t* stand for:

$$r = \cos\alpha$$

$$s = \sin\alpha$$

$$t = (1 - \cos\alpha)$$

As pitch and roll movements are two independent transformations with different angles and about different axes, two separate matrices have to be created. With the axes and angle convention given in Figure 1 and may $\vec{u}$ represent the position vector of one sensor, $\vec{u}''$ this position vector in its real orientation and $\vec{x}'$ the unit vector of the vehicle´s longitudinal axis rotated by the pitch angle, this leads to the equation:

$$\vec{u''} = \left(u_x'', u_y'', u_z''\right)^T = \left[R_{\vec{x}'}(\phi) \cdot \left(R_{\vec{y}}(\theta) \cdot \vec{u}\right)\right]$$

It is to be mentioned that the heading of the vehicle is disregarded. Thus the first rotation (pitch) is assumed to be around the global y-axis with its unit vector $\vec{y} = (0, 1, 0)^T$.

As it is only the vertical component of the rotated position vector $\vec{u}''$ which is necessary for correcting the depth, it follows:

$$depth_{corr} = depth_{raw} + u_z''$$

This error may be small but as it is only the static buoyancy affecting the vehicle, its spatial orientation is unknown. With vehicle lengths of several meters, a small pitch angle can cause a significant depth error. Similar to that, the values of ICASP´s PAR sensor can be corrected as well. Since the sensor is equipped with a so called Cosine collector, the measurement data varies with its inclination. The rotation matrices described before can also be applied in this case.
Currently, the previously described correction algorithms are part of the data post processing. However, as the PCC is a complete computer it is possible to execute all kind of correction algorithms while ICASP is still submerged.

3 Scientific Results

After the technological results have been described in previous deliverables, some scientific progresses which were accomplished using ICASP, shall exemplarily be shown here. One basic precondition of the scientific operations with ICASP so far was its deployment along with the water sample collector of AWI´s Bluefin AUV.

This sample collector has been developed in 2008 / 2009 independently from EUROFLEETS. Joined operations between ICASP´s fluorometer and the sample collector have already been presented during EUROFLEETS General Assembly No. 4 in Potsdam (October 2012).

The water samples of the AUV are used for calibration purposes and to validate ICASP measurement data. One example for data validation is the CO2 sensor whose values can be verified by measuring total alkalinity and dissolved inorganic carbon from water samples. Figure 2 shows sensor derived pCO2 data and sample derived pCO2 values in one plot (data recorded: 22.04.12, North Sea).

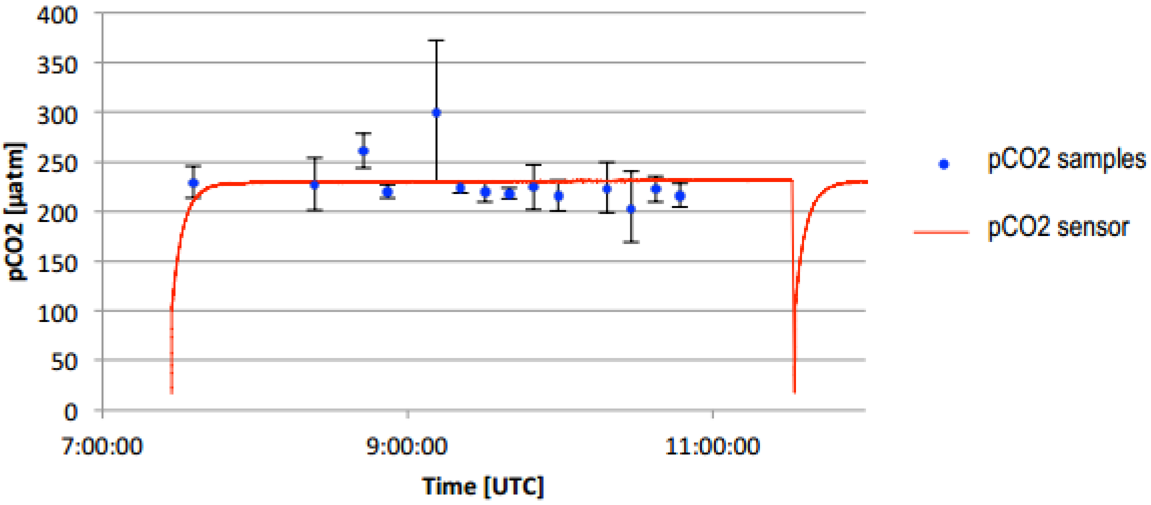

Figure 2: Comparison of sensor and sample derived pCO2 values: data validation

ICASP´s fluorometer is typically calibrated using AUV water samples. Thus, ICASP can deliver exact data on the Chlorophyll A distribution in the water. The following images 3a and 3b show the Chlorophyll A concentration at a polar water front. The data was recorded on June 30th 2013 during arctic expedition MSM 29 (RV Maria S. Merian, Fram Strait).

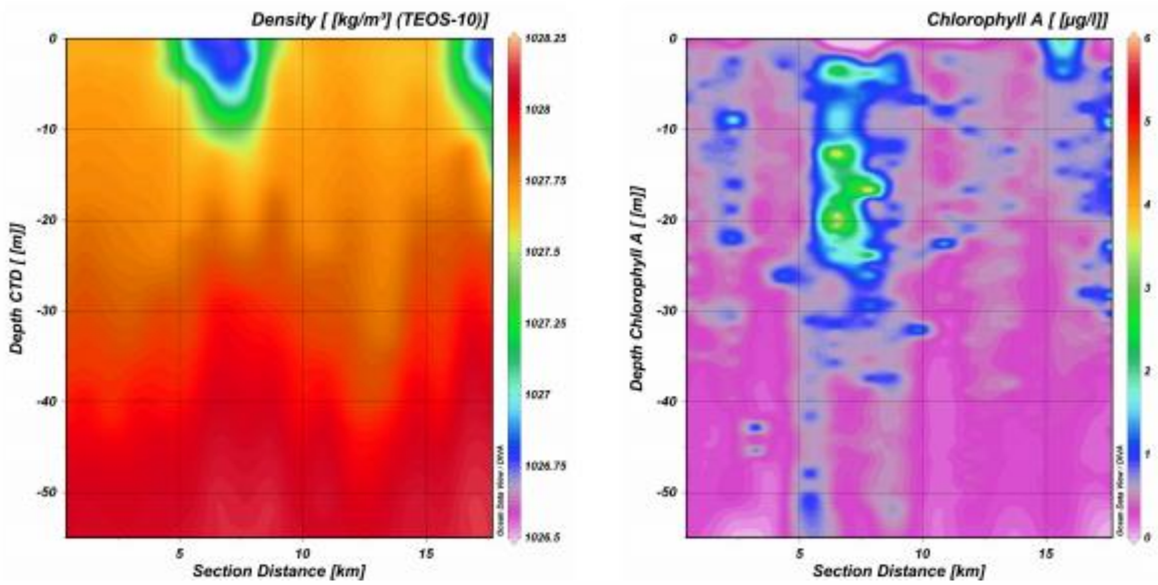

Figure 3: a) Polar water front marked by density gradients. b) Chlorophyll A distribution in this region.

The Chlorophyll distribution is measured based on the calibration curve given in Figure 4. This calibration curve was derived by simultaneously taken water samples.

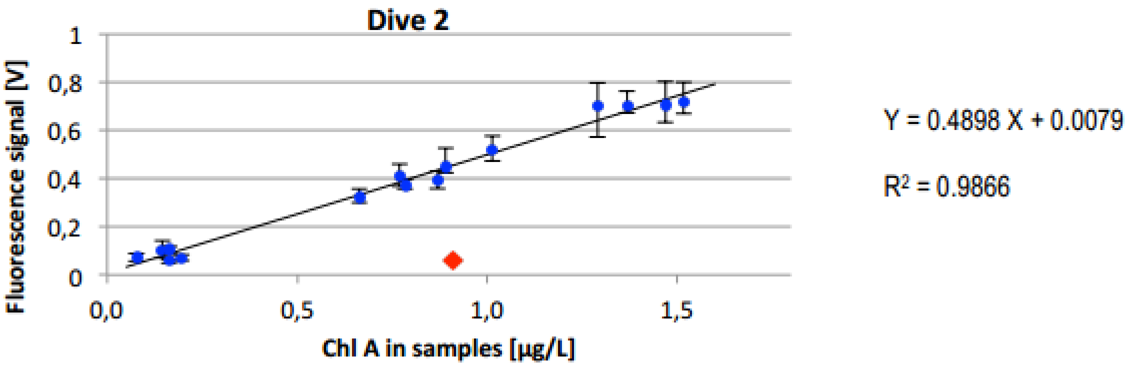

Figure 4: Fluorometer calibration curve used to create Figure 3b

Due to the different sensors which are integrated with ICASP other values can be included in the investigation as well. As an example figures 5a and 5b show CDOM and oxygen saturation values for the same deployment.

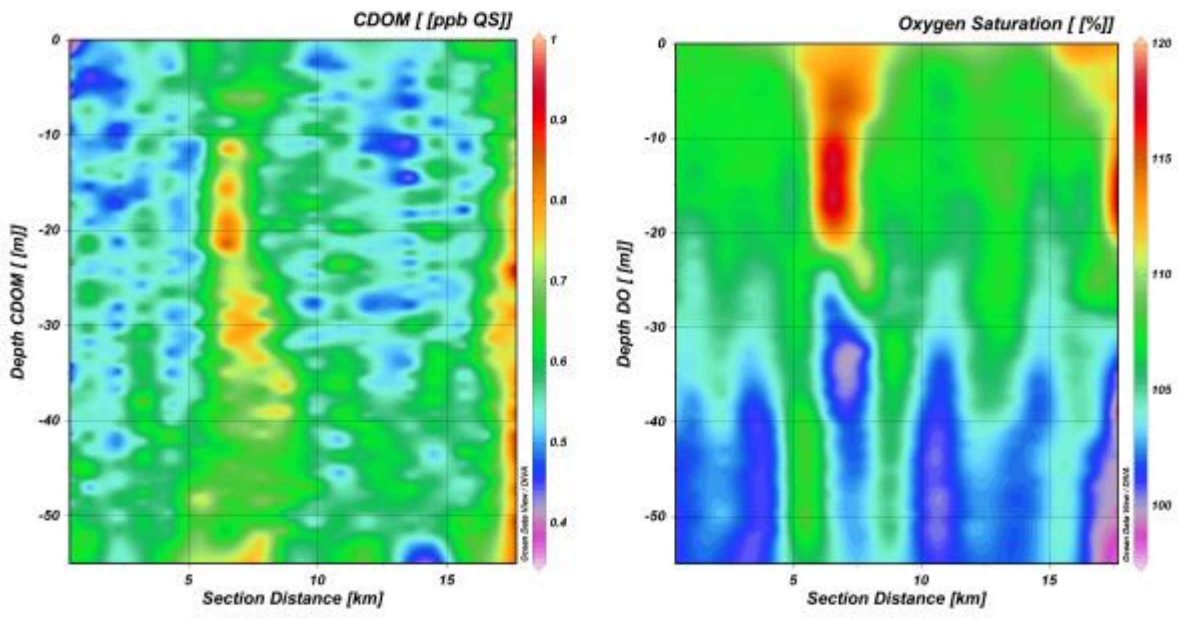

Figure 5: a) CDOM distribution at the polar water front of Figure 3a. b) Oxygen saturation at the polar water front of Figure 3a.

4 Problems

Using analog signals to transmit the data within the ICASP package turned out to be problematic. Especially the data of the nitrate sensor suffer from this limitation, as the sensor shows cross-sensitivity with bromide-ions and CDOM. In recent years a number of investigations have examined this problem resulting in correction algorithms for these errors. The sensor uses the absorption of UV-light to determine the nitrate value. The correction algorithms need to have the entire absorption spectra available. However, recording the entire absorption spectra using the analog output of the sensor is not possible. Instead, the sensor uses internally stored proxies to estimate the influence of bromide ions. Eventually the analog signal represents the nitrate value corrected by these proxies.
In order to minimize this error, the nitrate sensor is also calibrated using samples from the sample collector.

The CO2 sensor shows a relatively long response time. For this reason the uncorrected data of the sensor areof limited value for small scale investigations. As for the nitrate sensor, there are correction algorithms available to improve data quality. However, applying these algorithms requires an exact knowledge on the response times in different environments. The sensor´s response time depends on pressure and temperature. Thus the sensor´s response time must be determined at the "extremes" of a measuring campaign using a sensor feature called "Zeroing". For example, if ICASP is intended to be used in 200 and 100 meters depth, a Zeroing has to be executed in 200 and 100 meters depth. During arctic expedition MSM 29, the CO2 distribution between 50 and 3 meters water depth was investigated. In order to prepare the data correction process, the response time of the sensor was determined in 50 and 3 meters depth. Figure 6 shows the sensor signal during this dive along with the pressure and the sensor signal along with the temperature. The Zeroings can be clearly identified and look like "interruptions" in the sensor signal. After that the relatively slow increase of the signal towards a steady state can be seen.

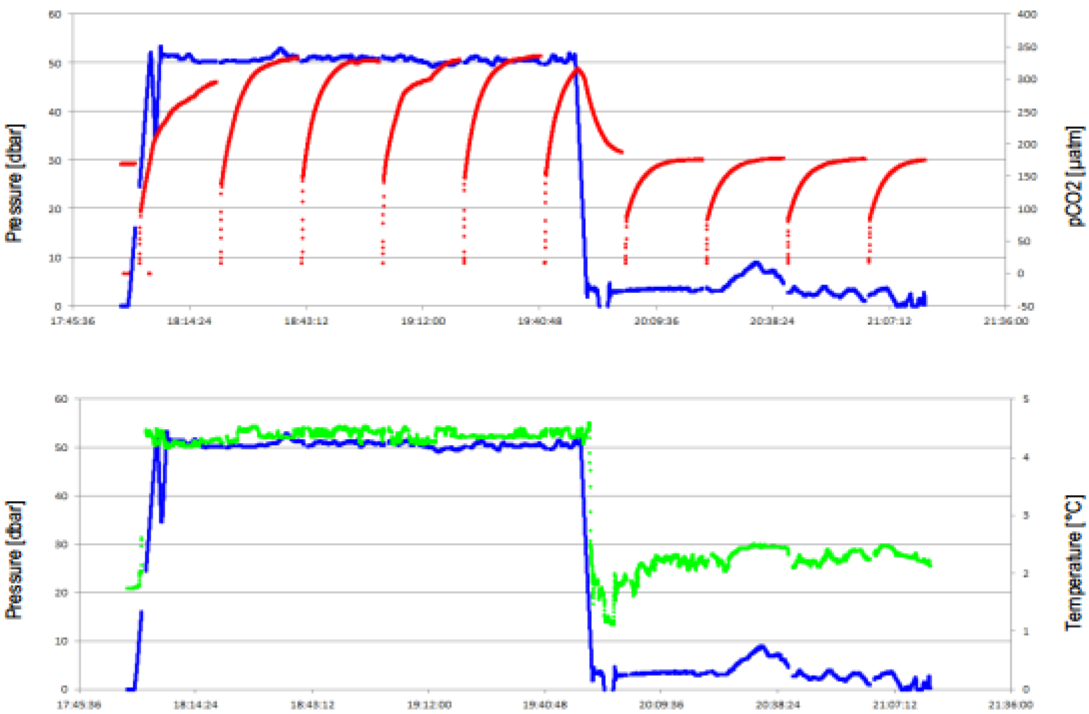

Figure 6: pCO2 values from sensor along with pressure and temperature.
● Pressure, ● pCO2, ● Temperature

As the water flow on the sensor´s measurement diaphragm is an additional variable in determining the exact response time it is an asset to complete the entire investigation while when the sensor is in its final configuration and assembly.

Part B: BGC Module Test Report

1 Introduction

An autonomous sensor module consisting of 4 sensors has been constructed (Fig. 7). According to the planned application the integrated amplifier can be exchanged and combined as required. Two autonomous BGC modules were built for deep-sea vent and seep research. Module-I consists of 1 pH, 1 temperature, 1 oxygen and 1 pCO2 sensor; Module-II consists of 1 oxygen, 1 H2S, 1 pH and 1 temperature sensor (Fig. 8). All sensor data are stored inside the pressure cylinder, which also contains the battery pack. For the autonomous mode an operation duration of ca. 45 hours has been achieved by integration rechargeable battery packs into the under water house.

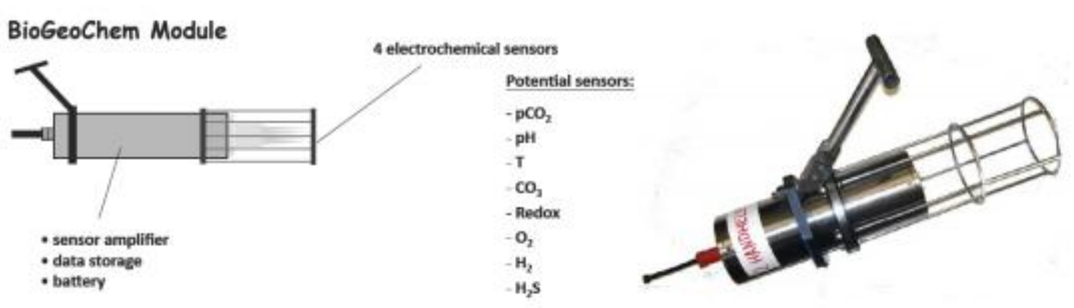

Figure 7: Four-Sensor-BGC-Module for biogeochemical measurements

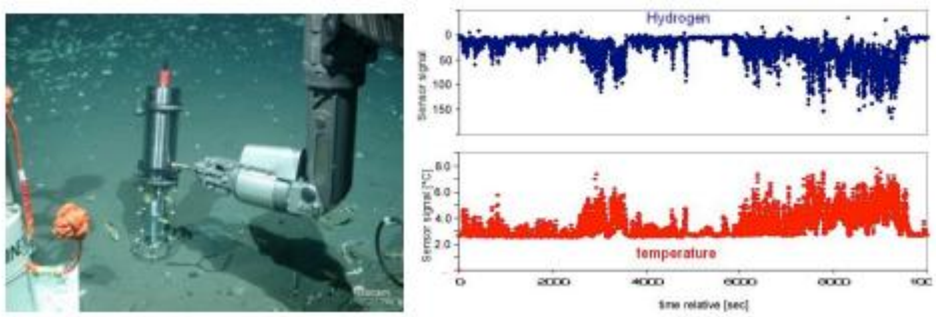

Figure 8: left: Example of an ROV operation using the handheld BGC-module to measure at a cold seep; right: Example of sensor data (hydrogen and T) measured with the microsensor-module at the hydrothermal vent site.

Additionally a new Modular Microsensor system (Fig. 9) has been designed and built based on the routinely used Microprofiler (MPIMM), which is able to carry up to 11 sensors. The new system allows connecting several sensor packages, data logger, underwater switches and motor controller to one operational unit, all interconnected via the MPI-Bus control system. The new system consists of several small 4underwater housings, which can easily be integrated onto different underwater platforms like ROVs, AUVs and observatories.

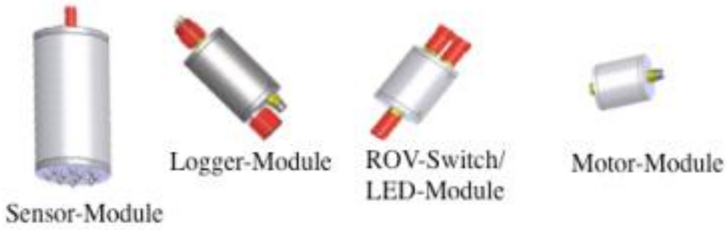

Figure 9: Components of the Modular Microsensor system

2 Scientific Tests

All modules (BGC and Modular-Microsensor-System) have been tested and used on a variety of national and international cruises and field campaigns. Some of the obtained results are presented here.
During a research cruise within the EU-project HYPOX the BGC-Module was used on the benthic crawler C-MOVE (Marum, Bremen) to measure high-resolution concentration gradients of O2, pH and H2S, and benthic fluxes in Black Sea sediments (Fig. 10). Because the crawler had an online communication via cable to the ship a direct control of the module was possible. This allowed performing high-resolution oxygen microprofiles within different habitats of the Crimean Shelf to study the effect of reduced oxygen availability on the benthic activity. The modular microprofiler was also mounted as a stand-alone system to the video-sensor-system MEDUSA (INGV, Rom) to monitor sulphide and oxygen in the water column.

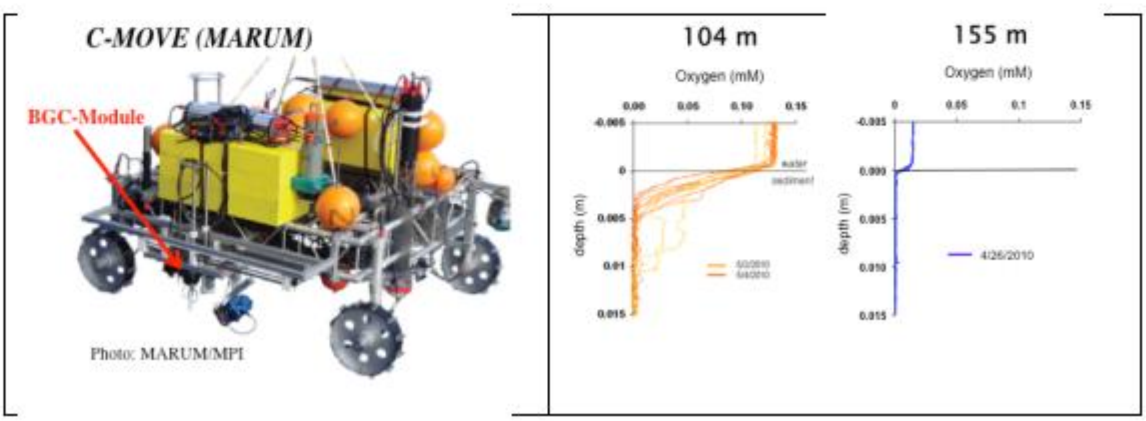

Figure 10: left: BGC-Module on the crawler C-MOVE (Marum, Bremen), right: Oxygen microprofiles measured at 104 and 155m water depth in sediments of the Crimean Shelf (EU-project HYPOX cruise MSM 15-1)

To monitor CO2 at natural and anthropogenic CO2 seeping sites within the EU-project ECO2 a handheldBGC-module was used in two different ways. First a standalone version was placed at a gas seeping site at the field site in Panarea to monitor the effect of emitting gas on water column parameters like CO2 and pH over time (Fig. 11). Secondly the BGC-Module was integrated into the payload of the AUV Bluefin (AWI, Bremerhaven, Fig. 12). A first test was performed together with the ICASP system of the Alfred Wegener Institute (AWI, Bremerhaven) during cruiseHE-377 at the natural CO2 seeps in the area of “Salt Dome Juist” (EU-project

ECO2). Extensive search grids with the AUV closely above the sea floor were performed in order to find natural CO2 seeps or CO2 leaks at the seafloor.

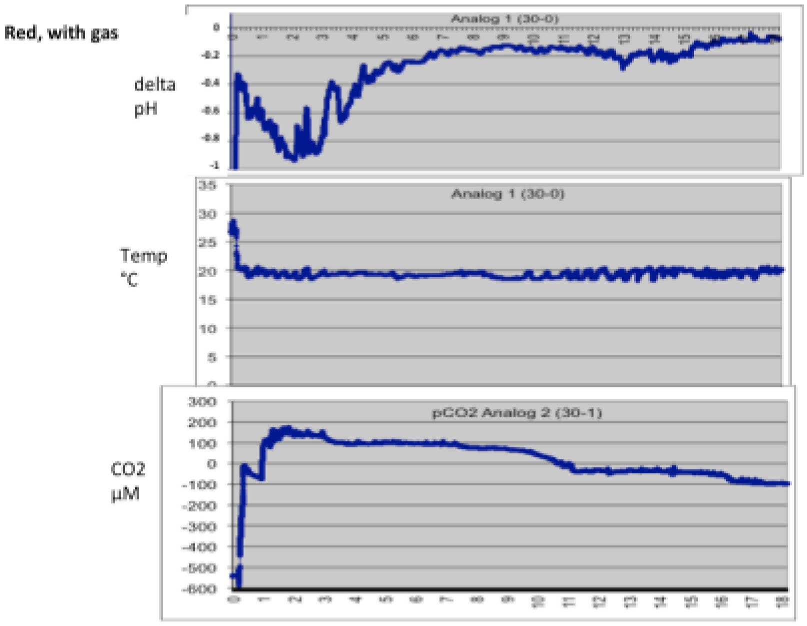

Figure 11: Monitoring of pH, T and pCO2 over a period of 18 hours at the CO2 seeping site at Panarea using the standalone BGC-module

During a second mission with the AUV Bluefine (AWI, Bremerhaven) during RV Polarstern cruise ARK XXVII-2 the BGC-module was used to monitor temperature and oxygen gradients under sea ice in the Arctic. Several dives were performed to monitor the chemical gradients in the upper water column and below sea-ice to get a better understanding of the biogeochemical processes in this fast changing environment.

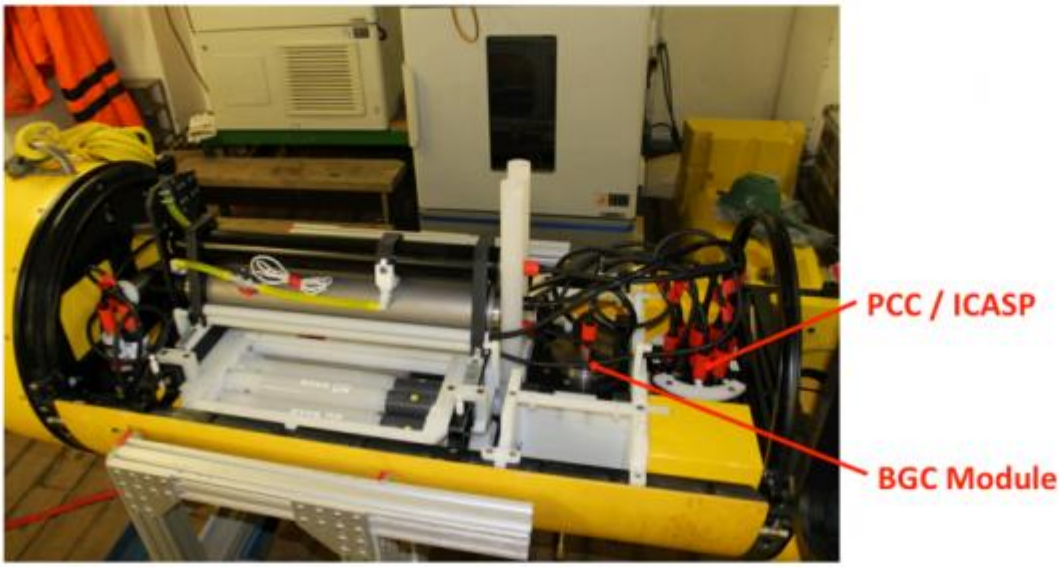

Figure 12: Integration of the BGC-module into the payload section of the AUV Bluefin (AWI, Bremerhaven)

3 Assessment

All sensor modules work fine and can be used on different underwater platforms. However, a skilled and trained person in biogeochemical sensor application is needed to run the systems. Sensors have to be calibrated before and after each deployment and obtained data interpreted in order to decide for further sampling. The later is especially true for real-time data monitoring. Future work will be to integrate these sensor systems into deep-sea observatories for long-term monitoring. This however, requires a further improvement of the power capacities (larger batteries or sleeping modes in between the measurements) and most important long-term stable sensors. A step into this direction will be the newly funded EU-project SenseOCEAN, were sensors for long-term applications will be developed. Also the microsensor-modules will be further developed for long-term deployments at deep-sea observatories.

Part C: 3D-HDTV Module Test Report

1 Introduction

The EUROFLEETS 3D HDTV camera incorporates an innovative technical approach to allow the installation / interfacing on a broad variety of platforms. Signal transfer can either be routed to the surface with a single standard Ethernet connection, or via a dedicated HDTV telemetry based on the HD-SDI data format at high data rates of 1.5 Gbit/sec. This allows a broader scientific use of such very high quality underwater images with 3D information as ever available before. Since many existing ROV or AUV platforms have the necessary space, power and ethernet connection interface already available. After launch to the scientific community, scientific use of the system will immediately include the investigation of deepwater corals, hydrothermal vents, coastal and shelf marine fauna, and gas hydrate and methane seeps – all of them demanding better visual documentation and higher quality acquisition of visual three-dimensional datasets.

A working scientific underwater stereo camera system (3D) with high definition quality (HDTV) was developed during the EUROFLEETS project. The system was developed by MARUM and IFREMER in cooperation with FRAUNHOFER IIS, Erlangen, for use aboard remotely operated or autonomous vehicles (ROVs or AUVs). It allows viewing, record and mapping live visual video information from the seafloor or from underwater objects in true stereoscopic mode, providing 3D information even with a limited bandwidth of scalable data transfer down to less than 10 Mbit/sec at25 frames/sec. In addition the system can be split to generate a Super Stereoscopic Video, or can be used as single or as two separated cameras connected over Ethernet or the HD-SDI interface.

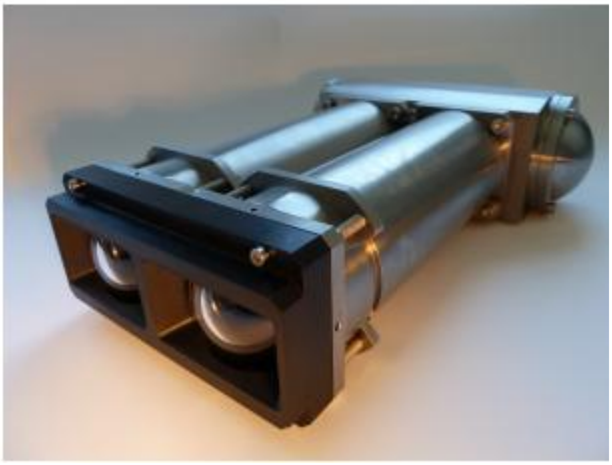

Figure 13: 3D-HDTV Camera in Stereoscopic mode

The main use of the camera will be the stereoscopic mode, with the configuration shown in Figure 13. The two cameras itself were develop by the FRAUENHOFER IIS and specially adapted to our requirements. The camera housing and the optics were developed at IFREMER and the additional electronics and control Software are in house developments of MARUM.

2 Scientific Tests

The 3D-HDTV Camera has been tested successful at the MARUM test basin with the ROV Questunder realistic field conditions.
The main test and most complex one was the 3D-HDTV Camera in stereoscopic mode with the Ethernet connection for video and control transmission.
The Figure 14 shows to top side test Setup. This was connected via the telemetry of the ROV Quest to the Ethernet interface of the camera. The setup allowed us a full test and will be used in the same way on the next ROV Quest excursion.
It consists out of four parts. The camera control PC that uses the MicroCamCtrl Software for 3D-HDTV camera control and monitoring. The ROV control Container video distribution, which converts the compressed video signal back to HD-SDI and shows the 3D video to the scientists and pilots. The MARUM DVR a digital video recorder support next to standard PAL and HD video recording also the compressed 3DHD contend of the new camera. And also the forwarding into a simulated ship network, to provide later on all scientists a direct live access to the 3D video stream.

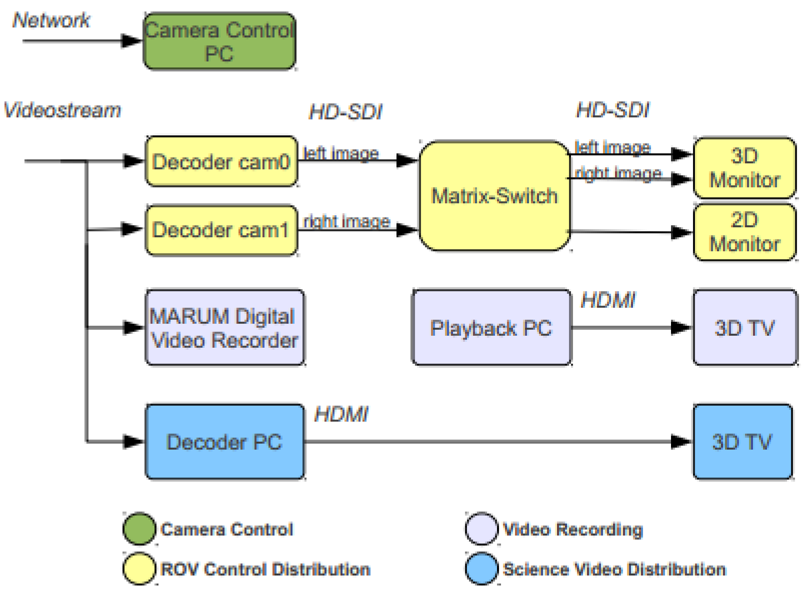

Figure 14: Overview top side test Setup

We also tested the HD-SDI connection of the cameras and the use of the separated camera Housings in our Labs. In addition for all housings a pressure test has been done and the depth rate of 6000m for the system could be verified.

3 Assessment

With the end of the project this final test showed us that the system is very stable and ready to use on by science. Even though the camera is easy to setup and to use with the control software, for a complex setup like the top side test setup with the Quest ROV a skilled and trained person in video distribution is necessary to setup the system.

We also recognize that with the use of the video compression the cameras have higher power consumption and get warm. We recommend not using the 3D-HDTV Camera outside of the water for longer than 15min. In water the cooling effect is high enough, that normal operation is possible without any constraints.
A second effect of the video compression and Ethernet video distribution is the latency of the overall setup. It is not possible with the current setup in the Ethernet mode to steer a vehicle. Even with Hardware Video encoding and decoding we have to face a delay of about one second. To avoid this Problem the 3D-HDTV Camera can be used in HD-SDI mode, but therefore two HD-SDI uplinks have to be supported by the telemetry system of the vehicle.
Over all we have a very good working 3D-HDTV Camera system, which is ready to use on the next excursions and we are looking forward to introduce these new way of 3D impression of the underwater world towards the scientists.
Due to the fast development of the video broadcast marked encoders and cameras getting smaller and less power consuming. There are already plans for a further development of the 3D-HDTV Camera system to be able to use it in real time for vehicle control or as standalone device with on board recording for 3D long term video surveillance.