UNIVERSIDADE FEDERAL DE SANTA CATARINA

INTERNSHIP REPORT

"Architecture and operation of the towed ocean profiler for the AWI (topAWI)"

Period: 7th May to 6th August 2018

Alfred Wegener Institut Helmholtz-Zentrum für Polar und Meeresforschung (AWI)

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August 2018 – Bremerhaven, Germany

The present report has as main goal to register Mr. *Neubauer'*s activities during his internship in the *Alfred Wegener Institut* as part of his bachelor's degrees in mechanical engineering.

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Preface and acknowledgment

For three months from 7th May till 6th August 2018, I did an internship at the *Alfred Wegener Institut Helmholtz-Zentrum für Polar und Meeresforschung* (AWI). Entitled as "Architecture and operation of the towed ocean profiler for the AWI (top AWI). The internship activities can be split into two main stages: initially, as part of the scientific crew on board of the RV *Polarster*n during the expedition PS113, where the intern joined the operational team of the project "System-Testing and commissioning of the multidisciplinary towed ocean profiler of the AWI (topAWI)" and in a second stage in a period after cruise, where the intern developed his activities in the city of Bremerhaven.

V.Strass, R.Knust 2018; *Polarstern*, Expedition *Programme* PS113

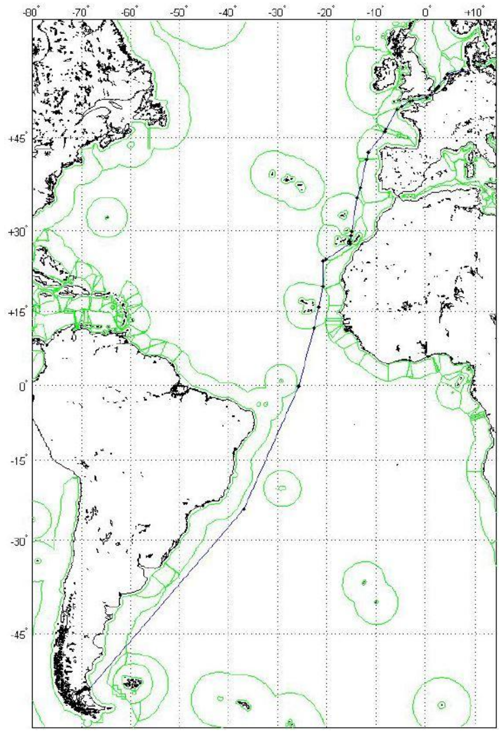

Figure 1: *Polarstern* track over PS113

The main goal of this report is not only to record Augusto's activities during his internship, however, but it also aims to point out the results and suggestions of the intern in order to aid future Triaxus operations. Therefore this document is written in a way that it can be read not only as a simple record report but also as an assessment report, according to the intern's point of view.

I very appreciate to Dr. Volker Strass and Mr. Hauke Haake, as well all the *Polarstern* and AWI crew, for this amazing and unique opportunity of doing my internship at the AWI and also participating of an expedition on board of the RV *Polarstern*. I will take with me during my entire career all the good examples that I saw and learned here.

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Chapter 1
Introduction

The oceans have a fundamental role in our Planet ecosystem, with all its immensity, even subtle changes can be of unestimated importance and its effects can act not only over marine life as also in our daily lives [1]. They play this key role, among other things by the sequestration and redistribution of CO_2, heat, and nutrients. To better understand the functioning of marine systems, with their high degree of complexity, measurements are needed that comprise the different disciplines and that are taken simultaneously over a very wide range of temporal and spatial scales and trophic levels [2].

Simultaneously measuring the relevant physical, chemical and biological variables with high temporal and spatial coverage and resolution in a quasi-synoptic manner represent a challenge that can be best met by towed undulating vehicles, as the vehicle-winch system Triaxus E [2].

Thinking in the need of doing this kind of measurement the AWI recently purchased the vehicle-winch system Triaxus E from the Danish company *MacArtney Underwater Technology*, a versatile, robust and complex system theoretically capable to achieve a vertical undulation range of 450 meters below the surface. One of the systems main characteristics is that it is also able to navigate to the side of the ship track, avoiding the turbulence and other interferences caused by the ship propellers.

As with any other new and complex engineering system, it needs to be intensively tested and assessed until achieving its best operation configuration and also to become a reliable and fully operational system. And is about that that the intern's activities mainly regards about. He concentrated his activities during the expedition to understand and learn how AWI implements the operation of a new system and also helping to develop new operational procedures. After the cruise, his activities were concentrated in the technical data recorded by the system during the expedition and also in secondary activities as media files management for training purposes for future expeditions, protocols enhancement, among others that are going to be described in the following pages.

1.1 Problem statement and main objectives

1.1.1 Problem Statement

As briefly described, the Triaxus E is a new system and despite being an equipment developed by the industry it was specially adapted to fit AWI's specific requirements. Therefore, Triaxus needed to be tested several times in its first expedition to achieve a real operational status and to seem like a reliable survey equipment. As also to train a crew to be acquainted with the system operation.

As cited in [2], “a complex, new and unique system such as topAWI needs intensive testing at sea after completion and initial instrument integration. Its operability on board of *Polarstern* will have to be assessed for different payload configurations and tow parameters settings”. Thus, the activities of this internship are part of the process of the operational implementation of the system as well as the afterward assessment with the aim to determine the best set of parameters for the system operation.

1.1.2 Main objectives

The main goal of this internship can be considered the active participation of the intern in the process described in the topic above, the system-testing and commissioning during the expedition and assessment of it. However, to make it clearer, the intern’s objectives are listed below:

1. Objective 1: participate actively in the expedition PS113;
2. Objective 2: help in the daily operation activities during PS113;
3. Objective 3: develop written procedures and visual images to assist in future operations and training process;
4. Objective 4: manage and analyze the data recorded by the system and generate automatically reports for basic data visualization.

1.2 Organization of this report

This report is organized into chapters, encompassing the expedition and work afterwards. The chapters are described as it follows in the next paragraph.

Chapter one gives the reader a brief introduction and an idea about the overall content. Chapter two is dedicated to giving an overview of the technical description of the system Triaxus E and its scientific payload. Chapter 3 is focused in the work developed during the expedition period and chapter four is for the period in Bremerhaven. And not-less-important the last chapter, the fifth encompasses the final considerations of the intern about the internship and suggestions for improvements that could be done for future works in field operations with Triaxus.

Chapter 2
Technical description

This chapter is dedicated to giving the reader a brief description of the system Triaxus E[1]. Firstly, is introduced a diagram which shows the whole system integrated and then, starting from the topside unit to the winch and vehicle is given a short overview of each part. Thereafter is presented a brief description of the scientific payload.

As some information, especially as regards to the Triaxus system, are confidential and should not be accessed by external personnel, the technical description is not very detailed in some subsystems. However, this section can give the reader a good overview of how the whole system works.

2.1. Triaxus E: a system Overview

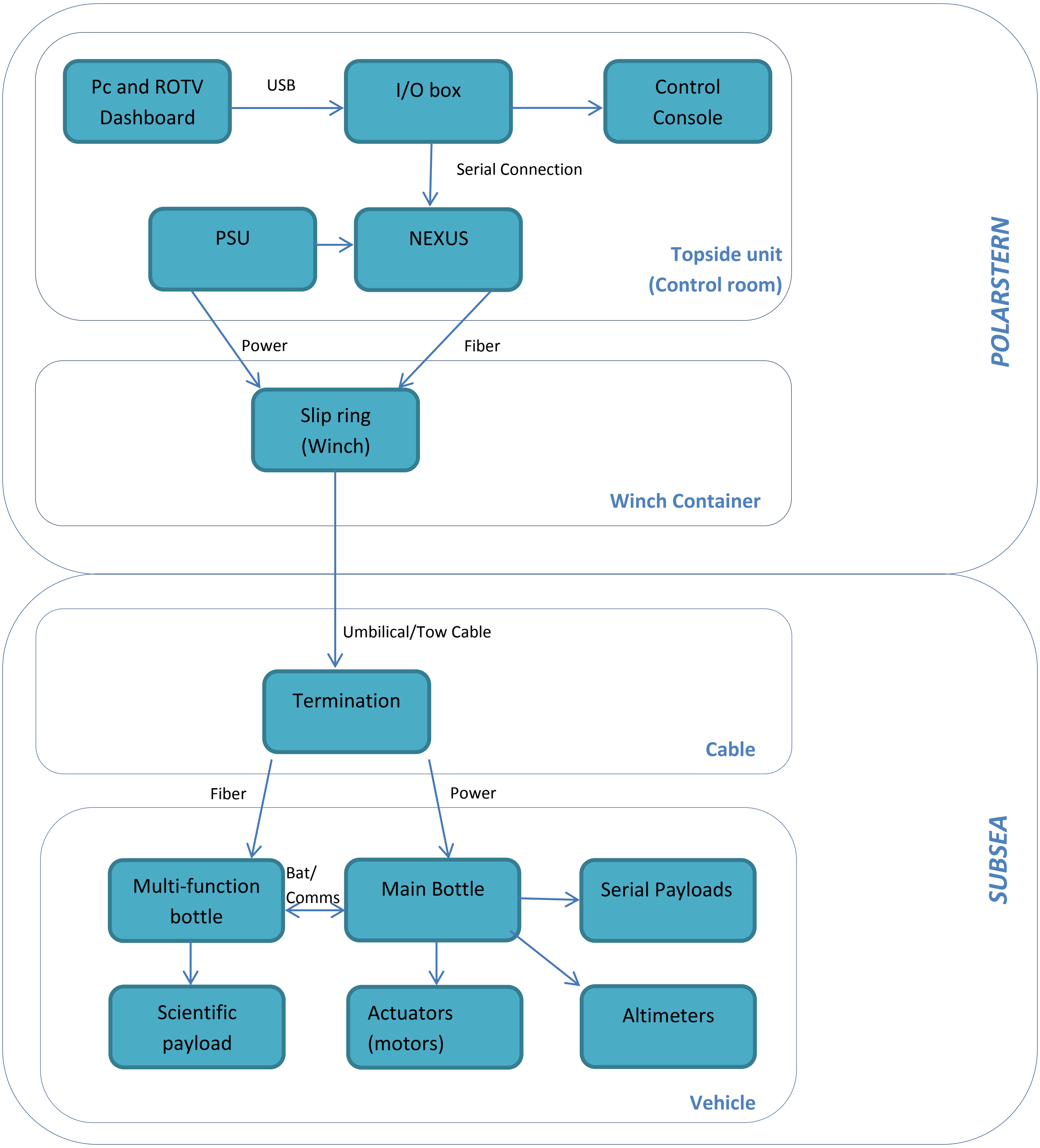
Triaxus E is a winch-vehicle towed system. Basically, the underwater vehicle is towed by a ship during its track and the winch is the connection among them. The system can operate in different modes in a *quasi*-automatically way.

The whole system is divided into four main groups. The topside unit, which is housed in the control room (in the case of Polarstern is the winch control room), the winch itself, that is housed in the container-winch on the working deck, the tether (or simply cable), that is composed by the towing and umbilical cable and also by the termination that connects the tether to the vehicle, and finally the vehicle, which works submerged in the sea.

For a better understanding of the system is essential to understand which are the main subsystems, their functions, and how they interact with other parts. This is a much-interconnected system, where many parts operate in a quasi-autonomous way reacting from the readings conditions of sensors in different parts of the system. Thus, with this purpose is presented in the following diagram, where the reader can visualize the main components and how they are interconnected.

[1] Much of the information contained in this section was taken from manuals [3] and [4].

System Triaxus E components diagram:



The following figure helps the reader to better visualize where each main block of the diagram is located:

Source: The author

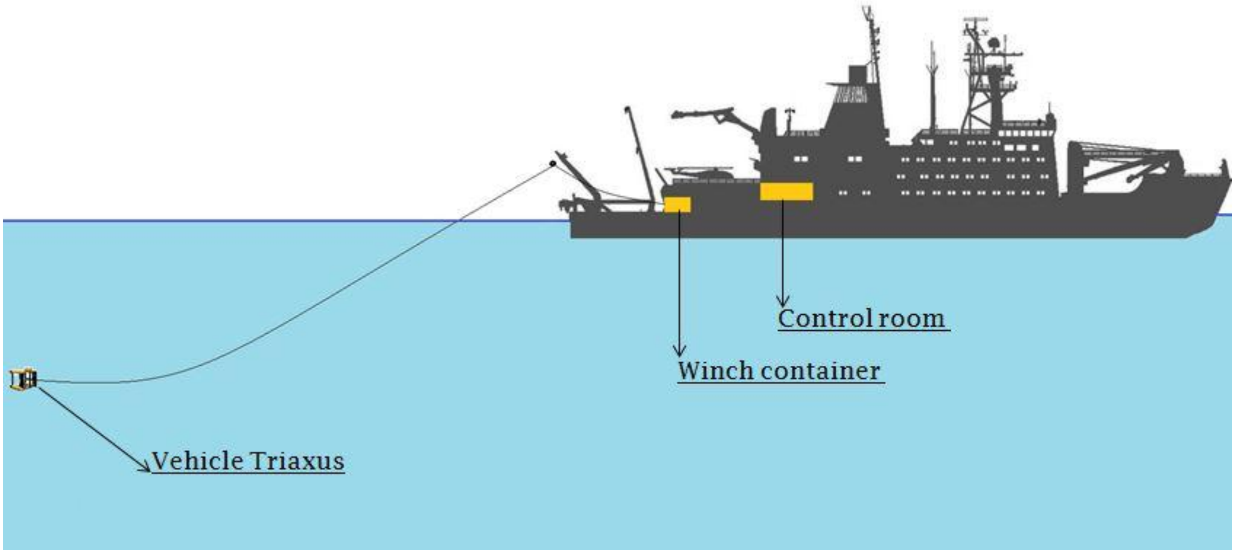


Figure 2: *Polarstern* and Triaxus

2.2. Control room description

In the winch control room of *Polarstern* is where the Topside unit of the system was located during the expedition PS113. In this room are two main systems: the control system of Triaxus and the monitoring system of the scientific payload which comprises several computers dedicated for constantly monitoring the sensors.

Source: The author

Figure 3: View of the control room

From this room, the pilot and co-pilot can control the vehicle and winch and also monitor all the sensors of the scientific payload. The following is a brief description of the main components located in the control room.

The room needs to have a proper passageway for the cables that make possible the communication and power supply from (and to) the vehicle and winch to the room. There are three cables that fulfill these functions: the **winch control deck cable**, the **vehicle power deck cable** and the **fiber optic deck cable.**

The **I/O Box** serves as a connection box to and from the Control PC as well as PSU interface pass through it. Already the **control console** is the system controller. From it is possible to control the vehicle, winch and the PC mouse. At the control console are to joysticks: one dedicated to the winch, where is possible to pay out or in the cable, and a second one, the “flap-control joystick” which is dedicated for the manual maneuvering of the vehicle. Then the subsea unit connection is achieved through the NEXUS telemetry system. All the vehicle communication and payload data transmission are routed via the NEXUS. The **PSU** is the power supply interface of the vehicle system. There is also a **PC** exclusively dedicated to the vehicle system, it is connected to the I/O Box and runs as a visualizer system for the pilot, from it is possible to see all the system and vehicle’s status and also play the commands to control it.

In the control room, there is also a PC for each scientific sensor, dedicated to the real-time monitoring of their data. The sensors are going to be listed on the vehicle’s description.

2.3. Winch description

The winch used in the system Triaxus E, manufactured by MacArtney A/S Company in Denmark, is the model MERMAC S20. Despite it being a maritime winch, with a certain degree of protection, the winch is placed inside of a container to shelter it against the harsh sea environment.

The S20 is an electrically driven winch [3] that can be operated from three different modes: local, remote and PC mode.

The local mode is when the winch is manually operated at the winch panel, in the container. By **remote** mode, the winch is operated from a wired control where is possible for the operator to control the winch on the working deck, this function is often used during the deployment and recovery operation, where is necessary for the winch operator to have visual contact with the system. On the **PC** control mode is where the winch is operated during the most of operation time. From the PC in the control room is possible to control all the winch function, payout or haul in the cable and also activate or deactivate the Auto Spool and Undulation Auto Spool modes.

Source: https://www.macartney.com/media/5276/mermac-s.pdf

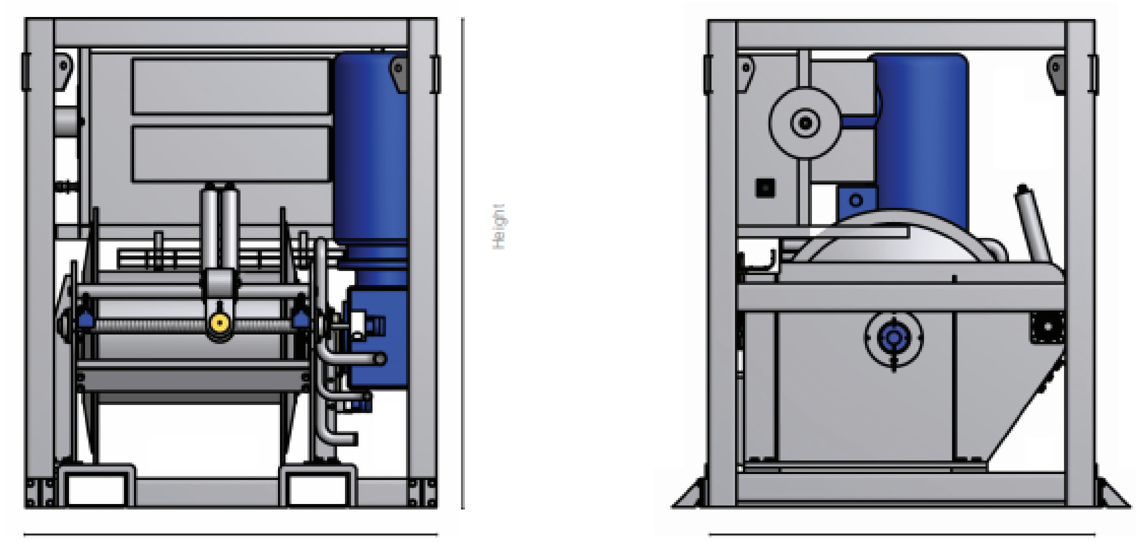


Figure 4: Winch frontal and lateral views

Source: The author

Figure 5: Winch container during a night operation.

The winch can be operated manually or in pre-defined modes. There are two main operational modes for the winch: the Auto Spool and Undulation Auto Spool.

Auto Spool: this function serves as instead of manually spooling the cable it is possible to auto spool to a defined length. After pressing the start button the winch automatically spools the cable at the entered speed until the desired cable length is reached [3].

The **Undulation Auto Spool** works when the vehicle is on undulation mode. It adjusts the cable length and cable spooling speed on basis of the cable tension in order to maximize the envelope.

The cable is both an umbilical and a tow cable. It is the route for the power that supplies the vehicle and for the communication between the on ship units and the underwater vehicle. The termination is the tow point where the tow cable ends and the vehicle is connected. The termination splits the umbilical into electrical and fiber optic connections [4].

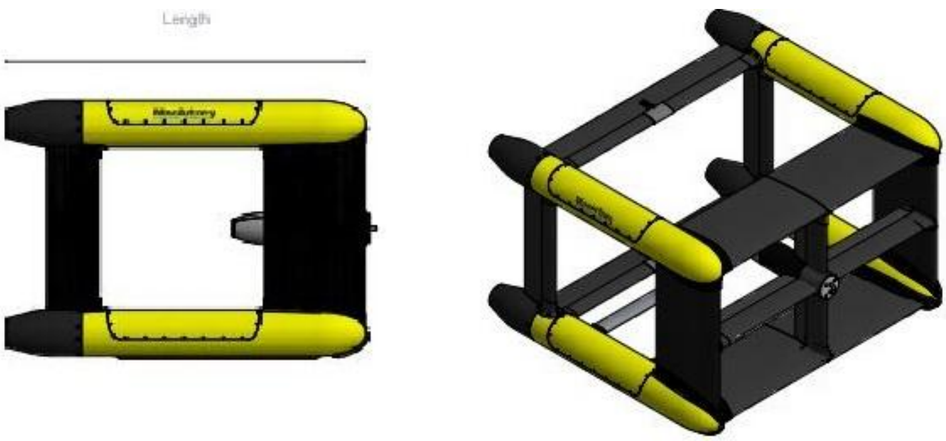
Termination safety: the stress termination includes a "weak-link" that protects the cable from being destroyed in case of the vehicle getting caught [4].

2.4. Vehicle Description

The vehicle is, along with the cable, the underwater part of the system. As the description in the technical manual: "Apart from generating the lift/drag required to reaching a certain depth, the vehicle is the platform, on which the subsea control system and the sensor packages are mounted" [4].

The vehicle is composed of four main tubes (bottles or hulls), flaps for pitch, yaw and roll motion control, and frames for placing the scientific payload.

Source: https://www.macartney.com/media/6445/triaxus.pdf (modified)



TRIAXUS E (extended version)

Envelope:	0-350 m* at 8 knots Using a 10 mm fibre optic tow cable
Tow speed:	2-10 knots*
Vertical speed:	5-100 cm/s
Payload:	50 kg
Dimensions:	(W x H x L) 1,950 x 1,250 x 1,850 mm
Weight:	130-170 kg (depending on sensor configuration)
Materials:	Syntactic foam, carbon fibre

Figure 6: Triaxus E view and main characteristics

2.5. Inside the hulls

Inside the lower starboard tube is located the **Main Bottle** (also known as Main POD) which is dedicated to interfaces to the vehicle control sensors and to the flap motors. The Main Bottle houses the vehicle controller, depth, pitch, and roll sensors[2] as well the DC power converter for both the main electronic PCB and the payload instrumentation [4]. Mounted at the lower starboard bottle is also an altimeter used to control the vehicle when it is near the bottom or to avoid obstacles as well as auto-altitude control. In total, there are two altimeters mounted in Triaxus, one upwards and the second one, as written, downwards.

On the upper starboard bottle is the **multi-function bottle**. This tube houses a battery backup to be used for emergency vehicle control [4], the telemetry system for high-speed communication interfaces [4] and other devices.

The other two bottles are used house scientific sensors and the electronics that give support to them.

2.6. Actuators

As described in the manual [4]: "The vehicle contains 5 actuators; they are stepper motors for flap control. A potentiometer serves as the feedback from the motor to the driver. The motor turns a maximum of 10 rotations. These 10 turns will take the control flaps from -19^o to +19^o – the maximum to minimum range. These limits cannot be surpassed. ±15^o limitations are introduced in the PC software. The flaps may stall if 15^o is exceeded".

2.7. Scientific payload

The main goal of Triaxus is to serve as a platform to mount scientific sensors. Thus, for an operation in order to prioritize a proper data acquisition is essential even for the technical staff to understand how the sensors work and what they are measuring.

During the PS113 Triaxus carried many types of scientific sensors. Following, there is a list of some of them and their purpose:

- **PAR** sensor: The **P**hotosynthetically **A**ctive **R**adiation is the spectral range of radiation from 400 to 700 nm. Phytoplankton and higher plants use electromagnetic energy from the PAR region for photosynthesis [5].
- **EK80:** the Simrad EK80 is an echo sounder system used to the assessment of fish and plankton biomass and its distribution [6].
- **SUNA:** the Seabird SUNA sensor is used to measure the nitrate in water. The nitrogen is released in water by a decomposing material such as plants, human and animal wastes. The nitrates are essential for plant growth as they facilitate the production of amino acids and proteins [7].

[2] In order to protect the information contained in the manual, this report is not going to encompass the vehicle 'sensors and neither their description.

- **AC-S:** is a spectral absorption and attenuation sensor. It can assess the water absorption and attenuation that provides a variety of information about an aquatic environment. When combined with CTD data can provide even more information about parameters such as chlorophyll, visibility, etc [8].
- **CTD:** Triaxus contains two CTD probes. The measuring of **C**onductivity, **T**emperature, and **D**ensity of sea water. The data can be used to calculate salinity, sound velocity and other parameters of interest, especially when combined with other sensors data.
- **ADCP:** the vehicle has two **a**coustic **D**oppler **c**urrent **p**rofiler (ADCP), one upwards and another one downwards. An ADCP is a hydroacoustic current meter similar to a sonar, used to measure the water column velocities over a depth range using the Doppler effect of sound waves scattered back from particles within the water column [9].

2.8. Operational modes

One of the greatest advantages of the system is its high degree of automatization. According to the mission purpose, is possible to set semi-automatic operational modes with which the system works with a minimum human interference. For example, if the Triaxus is being operated to do a survey of the seafloor using a side scan sonar, is interesting that the vehicle can maintain a stable and horizontal position in a constant depth, then, could be used the Auto Depth mode. Or perhaps, if we want to map an environmental property that varies with the water column depth, we could set the vehicle to the behavior itself in an undulation mode.

Along with the winch modes previously mentioned, also is possible to select operational modes for the vehicle. These modes can be selected on the PC control and are**: Tension mode, Slack mode**, **Auto Altitude**, **Auto Depth,** and **Undulation**.

The **tension mode** is used when the vehicle is towed near the seabed and allows the vehicle to escape obstacles with a steeper slope. For short cable length this mode may transfer some of ship movements to the vehicle [4]. However, when the vehicle is being towed by a long distance to the seabed and the operator is familiar with the area is possible to use the **slack mode**. The advantage of this last mode is that less movement may be transferred from the ship to the vehicle [4].

To have a trajectory that follows the seabed or the sea surface with a preset distance is possible to use the function **Auto Altitude**. However, if the interest is that the vehicle keeps in a preset depth the **Auto Depth** mode can be used. Along with these two functions is possible to set some others functions that can be used at the same time and “takes care” of the yaw and pitch flaps as such: the **Fixed** or **Auto yaw** mode and **Horizontal auto.**

The **Undulation mode** is used to undulate the vehicle in the water column. Along with this function is possible to set some safety modes for when necessary, the Turn and Follow. The **Turn** action forces the vehicle to turn when an obstacle is identified by the vehicle and the **Follow** action forces the vehicle to follow the seabed while an obstacle is identified. There are other two configurations that can be set in the undulation mode: the “Auto turn at” that enables the vehicle to turn before a set point to minimize the applied stress to the cable and the “Parking depth” that is used when the ship needs to make a turn [4] or when desired.

Chapter 3
Expedition PS113

After finishing one more Antarctic season, which started on December 20th, 2017, it was time for the *Polarstern*'s return journey to the homeport of Bremerhaven, Germany. As it is a transit cruise, at most of the time the ship was at an economically reasonable steaming speed.

Due to this transit characteristic, along PS113 there was not too many time available for stops for scientific stations. Therefore, the focus was laid on research work that could be done with the ship moving [2]. That turned the "System-testing and commissioning of the multidisciplinary towed ocean profiler of the AWI (topAWI)" to be the main scientific project conducted on board *Polarstern* during PS113.

The expedition started on 7th May 2018 in the Chilean city of Punta Arenas, a logistical stopover in Las Palmas, in the Canary Islands happened on 3rd June and the ship arrived in Germany late in the night of 10th June 2018 and the scientific crew left the ship in the morning of 11th June, in the city of Bremerhaven. Around 73 people were on board, 30 from the scientific crew and 43 members of the ship crew. In total the expedition took 36 days.

Along the expedition occurred 13 operations plus a static test. The longest deployment took place on May 24th and 25th in a 32 hours operation while crossing equator line from -2° degree south to +2° north.

In the image below is possible to visualize the days that the deployments occurred (in dark blue). Each block of this bar is a day of the expedition.

Source: The author

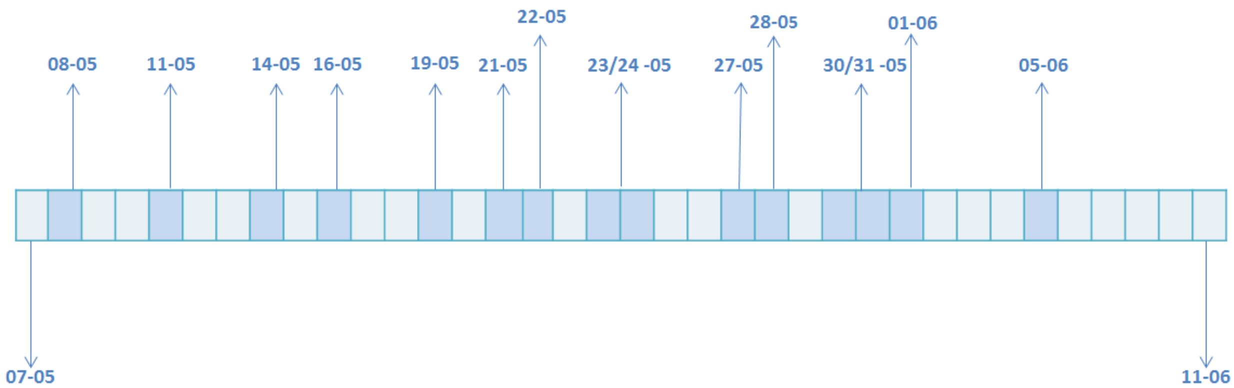


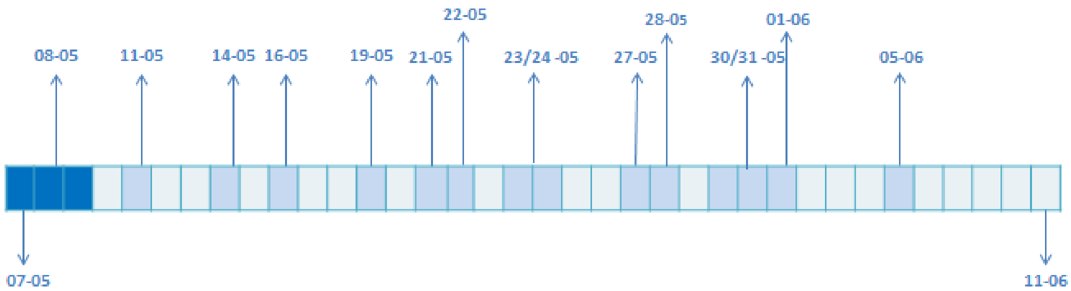
Figure 7: Days of Triaxus deployment, in dark blue.

“A new and complex, new and unique system such as topAWI needs intensive testing at sea after completion and initial instrument integration. Its operability on board of *Polarstern* will have to be assessed for different payload configurations and tow parameters settings” [2].

As described in the previous sections, as well in [2], the intern participated of the project “System-Testing and Commissioning of the Multidisciplinary Towed Ocean Profiler of the AWI (topAWI)”.

Along this chapter is going to be described the activities of the group topAWI in the process of testing and commissioning the Triaxus system. As well the intern’s participation.

3.1. Unboxing, preparation and the first static test



The first days on board of *Polarstern* were dedicated to the preparation of the system for the upcoming tests at the sea. On May 7th the work was focused to unbox Triaxus that was stored in the main wet lab and to install the main sensors to have a real approximation of the mass distribution on the vehicle, as part of the preparation for the **static test**.

The goal of the static test is to ensure that the vehicle is level at sea when placed in the water. Therefore, in the afternoon of May 8th, the vehicle was placed by the lateral crane in the water while the ship was still in the harbor of Punta Arenas. The team verified that the portside of Triaxus was slightly deeper in water then the starboard side.

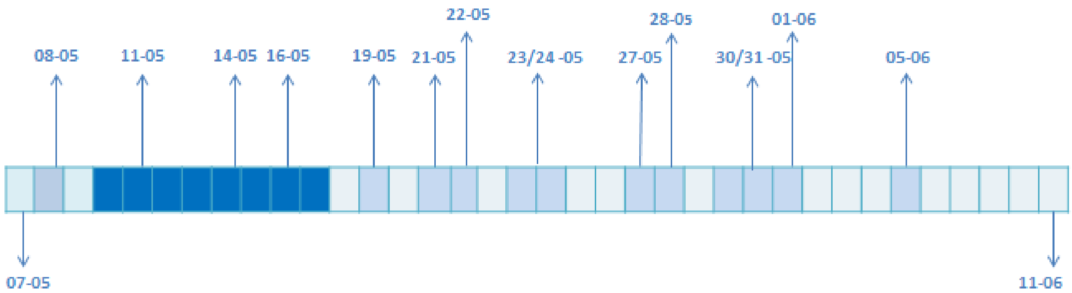
After the test, the vehicle was taken out of the sea and as always the first thing done was to flush the vehicle with fresh water. In the hours after the team opened the system and in the next day with the aim to correct the level line of the system, some foam was added in the starboard side of the vehicle, in the upper bottle.

Source: The author

Figure 7: Triaxus during the static test. The starboard side appeared to be slightly deeper in water.

The works of May 9th and 10th were dedicated not only for the vehicle Triaxus itself, however, for the installation of the whole system. The energy on the winch container was established. The cabling linking the control room to the winch and vehicle was also installed as well the two scroll blocks for the towing cable.

3.2. First deployments: narrowing confidence with the system



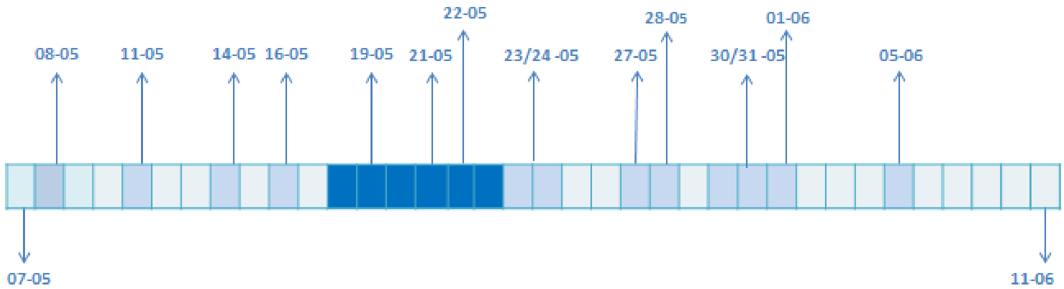
The first deployments had as main goals to make the team familiarized with the work and turn the system reasonably reliable for the upcoming tests, where we would need to have the system prepared and running well to be able to collect scientific data properly.

These operations developed gradually, testing basic commands of the system and operational modes, as well pilot training. Those first deployments were fundamental to establish a work routine and to assess the system performance. As one of the goals of the expedition, the team started to develop some procedures to assist and the follow by the operational team. Many sensor adjustments were made in these deployments.

During these deployments, the system showed up some issues when requested to operate in the Undulation mode and Auto-Spool simultaneously. And also showed up some CPU overheating alarms, which is going to comment further in this report. Even so, no operation needed to be canceled. Despite these small issues, for being the first tests of a complex system and with a completely new team, it can be considered a technical success.

All these work was gradually and continuously assessed and improved during the expedition.

3.3. Sensors calibration and GAPS Test



After the first three deployments the operations started to be refined. Once the team was already familiarized with the system, as part of the process of sensors adjustment was necessary to calibrate the vehicle's ADCPs and perform the first test with the GAPS system.

The first of two deployments with a GAPS system occurred on May 25th. The Global acoustic positioning system, also known as GAPS is an underwater positioning system used for tracking the Triaxus while in operation. The system consists in a transceiver mounted under the ship hull and a transponder/receiver mounted on Triaxus. The transceiver is an IXSEA GAPS USBL which is mounted on a pole under the ship, it combines USBL (ultra-short baseline), INS (inertial navigation system) and GPS (global positioning system) systems. The transponder mounted on Triaxus is a MT9x2s.

For better understanding how this positioning system works, detailed information can be found in [10].

Despite the team knows the cable length, depth of the vehicle and GPS position of the ship, is not possible to know exactly where the actual Triaxus position is. Thus, the GAPS data is essential for better understanding the equipment behavior during the operations. One of the major limitations of using GAPS is that the ship speed needs to be relatively slow, around 6 knots, when comparing with an operation without GAPS that is around 8 knots. Considering the high operational costs involved in an expedition in a ship such *Polarstern* is crucial to develop a method that could be able to estimate Triaxus position without the need of a so slow speed.

Source: the author

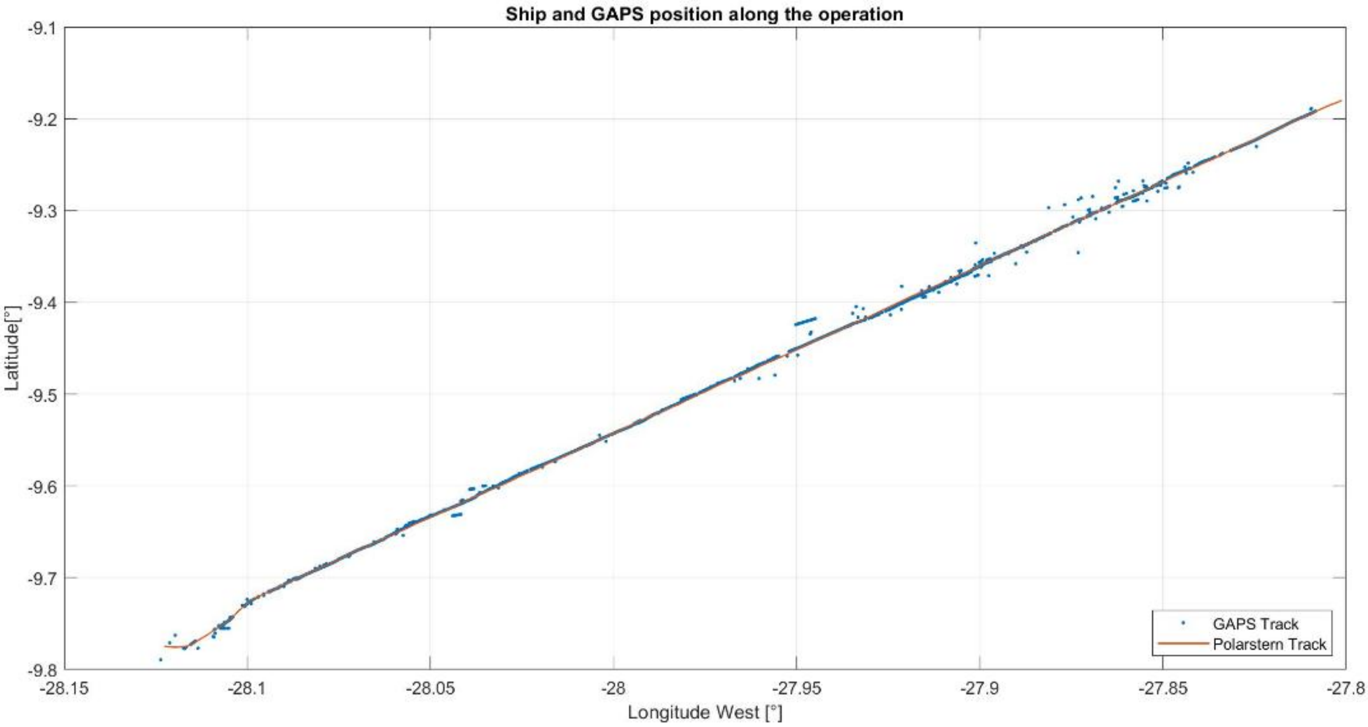
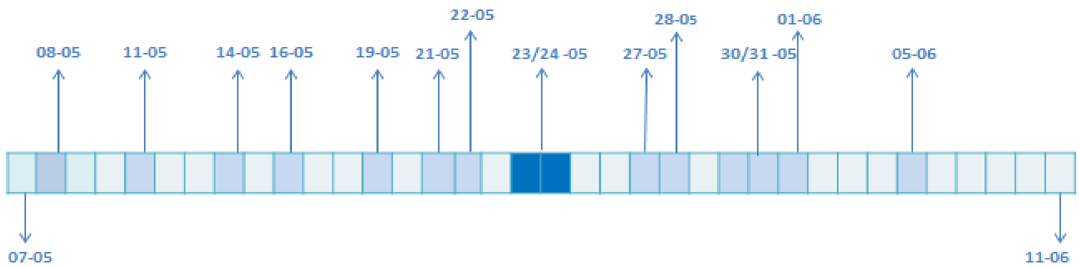


Figure 8: In blue the GAPS position and in *red Polarstern* track

The information obtained during the GAPS test will have great importance for assessing, in comparison with other data, which parameters can influence the vehicle's behavior and then help to create a model to estimate Triaxus position without the need of using a GAPS system.

3.4. "Mission Equator"

Between May 23rd and 24th occurred the most valuable deployment in



scientific meaning. The Atlantic Equator region has a net of transport of heat from the southern to northern hemisphere, mainly because of the intense, cross-equatorial coastal North Brazil current [11]. The equator currents play a central role in Earth's climate, by influencing sea surface temperature patterns for example [11].

In order to visualize the different parameters in water column along the Equator mix layer, specially about the Atlantic equatorial countercurrent, the topAWI group organized a 32 hours long deployment for crossing the Equator from – 2^{o} degree south up to $+2^{o}$ degree north. For this long deployment, the team was divided into small operational groups of three members and in shifts of four hours of work and eight hours of rest.

In the image below is possible to visualize the operational area.

Source: the author

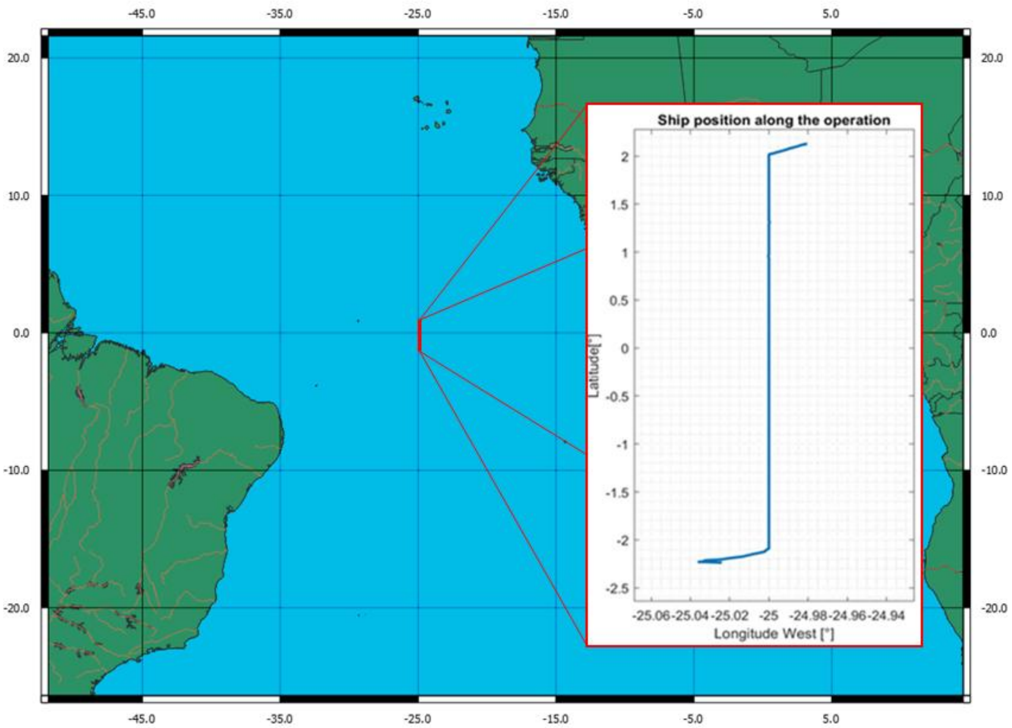


Figure 9: "Mission Equator" operation area

In order to map the water column with a high spatial resolution the system worked in an undulation mode during these 32 hours under the operational parameters:

Table 1: Operational parameters used while crossing equator

Operation Mode	Undulation
Min. Depth	5 m
Max. Depth	300 m
Vertical Speed	1 m/s
Cable Length	1800 m
Yaw flap Command	0^{o}
Ship speed over ground	8 Knots

Thus, the vehicle was able to complete an undulation period approximately each 11 minutes, which can be seen in the graph of Depth of the vehicle *versus* time.

Source: the author

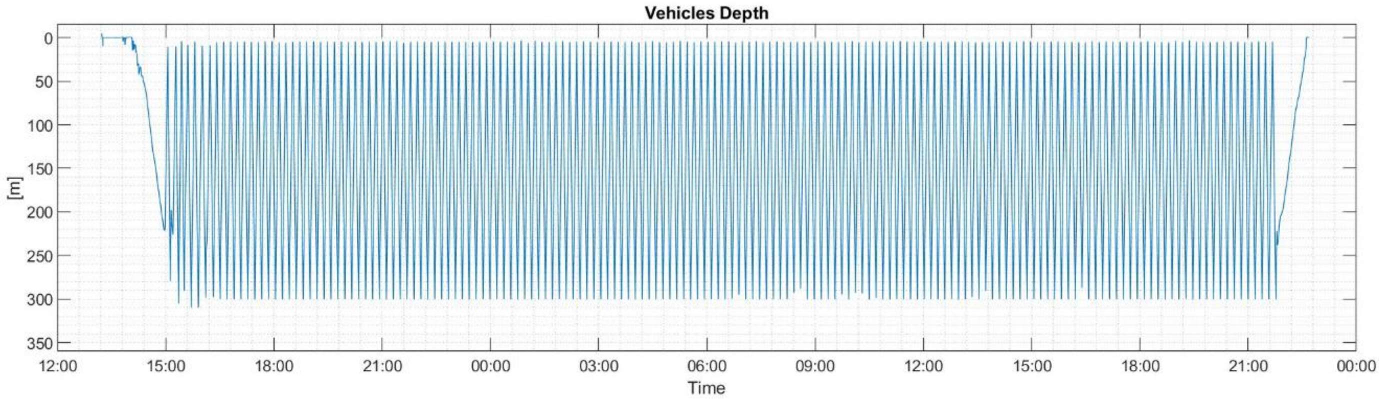


Figure 10: Triaxus depths over time

After the operation, with the data collected, even in the ship yet and thanks for the brilliant work of Dr. Wilken-Jon Von Appen and Dr. Volker Strass was possible to visualize the results of the operation. These graphs bellows give the reader a sense of how powerful the Triaxus system can be and the type of results that are possible to be achieved. It is very important to point out that only a few of the following graphs (the first two rows) were generated by Triaxus sensors, while others color graphs were generated by derived data from Triaxus sensors and other on ship equipment.

Source: Dr. Wilken-Jon Von Appen, Dr.Volker Strass, *Alfred Wegener Insitut*

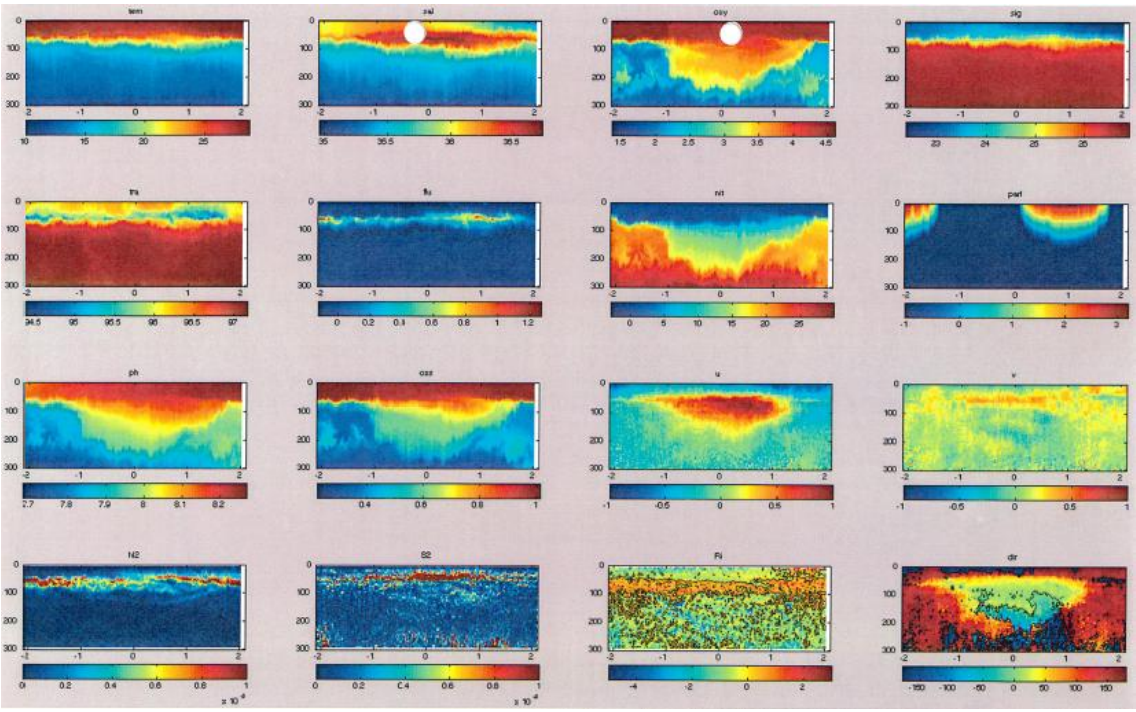
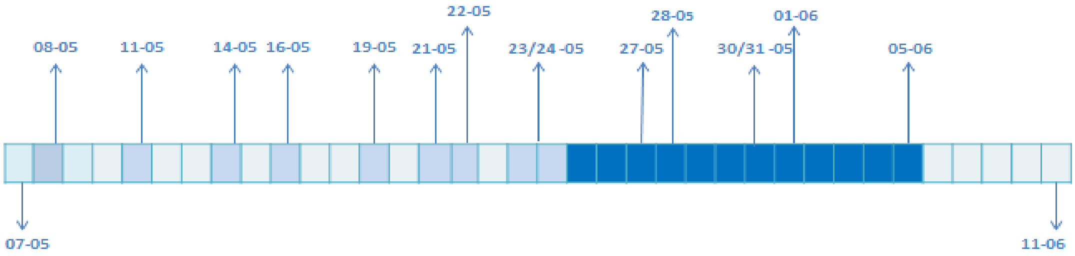


Figure 11: Example of the kind of results that can be achieved with Triaxus

3.5. Operation in Biscay and last deployments



After the deployment in the Equator, in the northern Atlantic, more five deployments happened.

The deployment 027_03, on May 27th, had as the main goal to test the Undulation with Auto spool mode that during the first deployments was not able to be used.

The deployment 028_03, on 28th, served as a test to assess the flight performance of Triaxus with a ship of 10 knots speed. Due to the reasonable higher speed, during the undulations, the system indicated many overloaded turnings. This deployment is going to be better commented in the after cruise work section.

The deployment 029_03, on May 30th, was another long operation in the upwelling Eastern Atlantic region. As during the Equator operation, the team was organized in groups of three working in four-hour shifts.

On June 1st, occurred the second and GAPS test.

For legal reasons, the AWI is only allowed to develop its researches in international water. Therefore, the opportunity for the last deployment was on June 5th between the waters of *Cabo Verde* and mainland Portugal. As it can be seen in the image below.

Source: the author

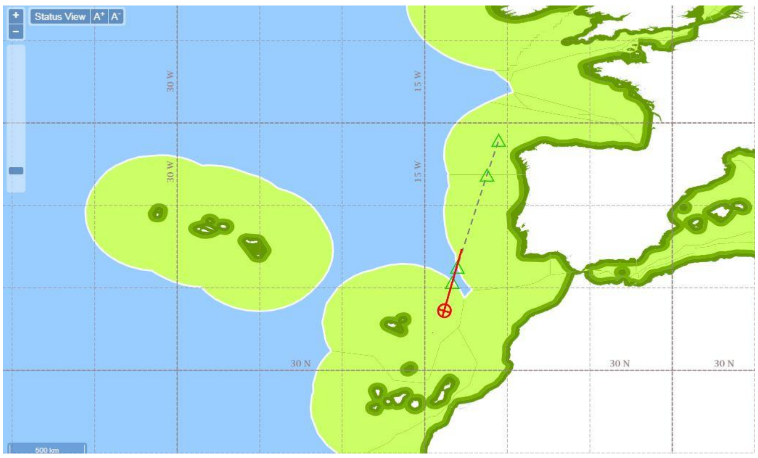
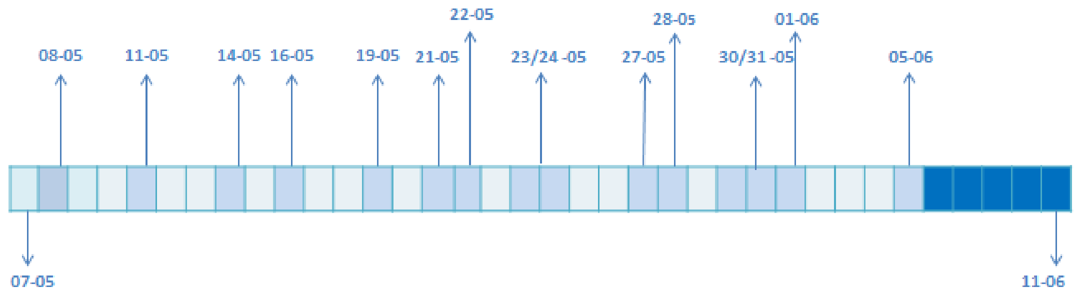


Figure 12: Last corridor of international waters in PS113

3.6. Packing Triaxus



The last days of the expedition were dedicated for cleaning and packing the system for its storage and later transport from the harbor customs area to the AWI.

3.7. An overview about the routine of operation

This section has the aim to describe the routine of operation during PS113. The process described here was applied and improved continuously along the several deployments.

The operation of Triaxus encompasses six processes, which are represented in the following diagram.

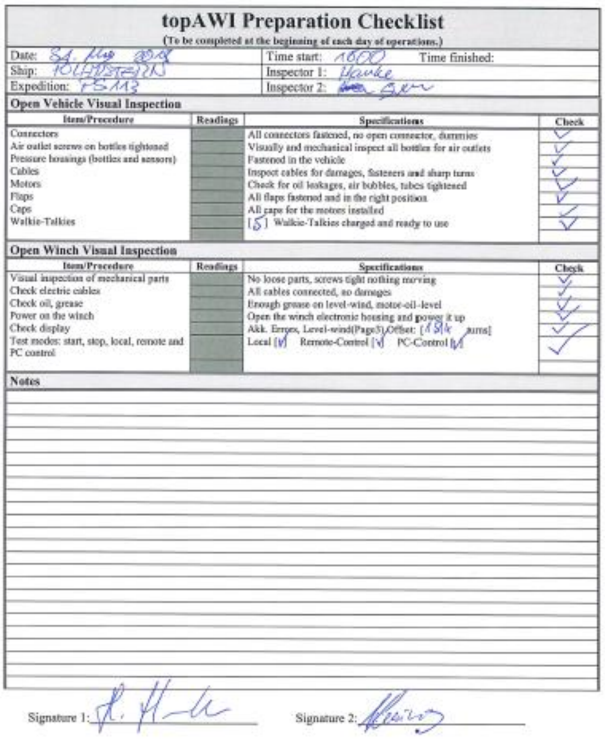
Source: the author

Figure 13: Processes involved in daily operation

Before any operation, a preparation of the equipment used is needed. The **preparation for the deployment** is done in a day before (or in the night after a deployment and before the next one in the day after). This process has the goal to do the daily maintenance of the system and keep it in operational conditions. Besides that, is recommended to do this activity one day before the deployment to prevent possible delays in the deployment schedule. It consists of a simple external visual inspection up to open the motors fairing to verify their integrity. To assist the operation personnel, a "description of procedure" based on a checklist with orientations was developed during PS113, it is called "***Preparation Checklist***". An example of this document[3], used in the expedition, can be seen below.

[3] All the documents developed to assist the operations are available in the folder provided by the intern. In this section are only some exampled used during the expedition. A newer version was improved by the intern during the after cruise work.

Source: the author



topAWI Preparation Checklist

(To be completed at the beginning of each day of operations.)

Date:	Time start: 1600 Time finished:
Ship:	Inspector 1: Hauke
Expedition:	Inspector 2:

Open Vehicle Visual Inspection

Item/Procedure	Readings	Specifications	Check
Connectors		All connectors fastened, no open connector, dummies	✓
Air outlet screws on bottles tightened		Visually and mechanical inspect all bottles for air outlets	✓
Pressure housings (bottles and sensors)		Fastened in the vehicle	✓
Cables		Inspect cables for damages, fasteners and sharp turns	✓
Motors		Check for oil leakages, air bubbles, tubes tightened	✓
Flaps		All flaps fastened and in the right position	✓
Caps		All caps for the motors installed	✓
Walkie-Talkies		[5] Walkie-Talkies charged and ready to use	✓

Open Winch Visual Inspection

Item/Procedure	Readings	Specifications	Check
Visual inspection of mechanical parts		No loose parts, screws tight nothing moving	✓
Check electric cables		All cables connected, no damages	✓
Check oil, grease		Enough grease on level-wind, motor-oil-level	✓
Power on the winch		Open the winch electronic housing and power it up	✓
Check display		Akk. Errors, Level-wind(Page3) Offset: [turns]	✓
Test modes: start, stop, local, remote and PC control		Local [✓] Remote-Control [✓] PC-Control [✓]	✓

Notes

Signature 1: Signature 2:

Figure 14: Example of Preparation checklist

About one hour before launching Triaxus in water is executed the "**Pre-dive checklist".** It is a process that serves to initialize the system and realize the verifications that only can be done with the system energized. A final visual inspection, checking the team positioning and the flaps maneuvering are examples of activities that are done is this procedure. Based on the time notes made by the intern, the average of time to execute this stage is around **30 minutes**, however, is recommended to reserve **one hour** for this task, for in case of any issue is detected and a correction is needed.

After the Pre-dive checklist is time for **launching**[4] the system on water. This task must be done with the deck's crew assistance, the *A*-frame crane is also necessary to lift up the vehicle. In total, around **20 minutes** are necessary to do this task.

The next step is to change the winch control from the winch operator on deck to the PC, under control of the pilot in the control room. This part of the operation is when the measurements are taken. Around **90% of the operation time** consumed at this task.

[4] Images from launching and recovering the system are also available in the folder provided by the Intern.

Source: the author

Figure 15: Launching the system

During the operation, at least three people are necessary to run the system: the pilot, co-pilot and a third member. The pilot has the task to control the system via PC, the co-pilot besides to assist the pilot has a duty to take notes about everything that happens during the deployment to record it in a document named "**Dive log**", and the third member is responsible to assist the pilot and co-pilot in general tasks, check the winch on deck and if the sensors are working properly. Very similar to the launching but in a reverse direction is the **recovery** of the system.

Source: the author

Figure 16: Recovering the system, view from the deck.

Once the vehicle is safe on deck is time to start the **“post-dive check list”.** It is a procedure to inspect the system and verify any possible damage to the vehicle that could have happened during the operation. After each operation the vehicle is flushed with fresh water to minimize the effects of corrosion caused by the salt water.

Chapter 4
Work after cruise

This chapter is going to describe the work done by the Intern during the period after the expedition at the Alfred Wegener Institute in Bremerhaven, Germany. In the following eight weeks after the cruise, the intern worked with the data recorded by the system during the deployments to try to understand the main operational parameters and how they are correlated with the behavior of the vehicle. The intern also edited media files for being used in future training, improved the procedures developed by the team during the expedition and meet projects at MARUM and at the Max Planck Institute for Marine Microbiology in a one-day visit in Bremen.

4.1. Data Analysis

Most of the work time after the cruise was focused on the data recorded by sensors during the expeditions. Is essential to make clear that the data which the intern worked with is not from the scientific payload, but from the sensors used to read and control the technical data of Triaxus.

While Triaxus is on operation a set of sensors are used to read the inner and external conditions of the system. All the readings of these sensors are recorded and can be assessed after the operation.

The software used is the Matlab® from MathWorkS Inc. The data generated by the sensors were converted from raw data to Matlab files according to the protocols descriptions provided by MacArtney. The data was converted by Dr. Wilken-Jon Von Appen then, the intern only needed to focus on the data visualization.

The **methodology** of the intern's work was based **in reading the dive-logs** written by the pilots during the operations, and from there he **identified** the main issues that occurred along the mission. Then, first, he plotted the data to **visualize** the problem and finally tried to understand **why** or **when** it occurred. Based on his results he suggested some attitudes that can be done to prevent those issues.

4.1.1. General Reports

The first two weeks were dedicated by the intern get familiarized with the data and for general visualization. As a result of this work the intern created to files to try to compile as maximum as possible of different system in a same. The scripts used to generate these reports are available in the folder provided by the intern.

However, as an example, in this section is going to be presented the main plots of these reports. In this particular case, the data is from the deployment 020_02 of May 20th, 2018.

All the reports[5] start with a general section, where is presented the main characteristics of the fight.

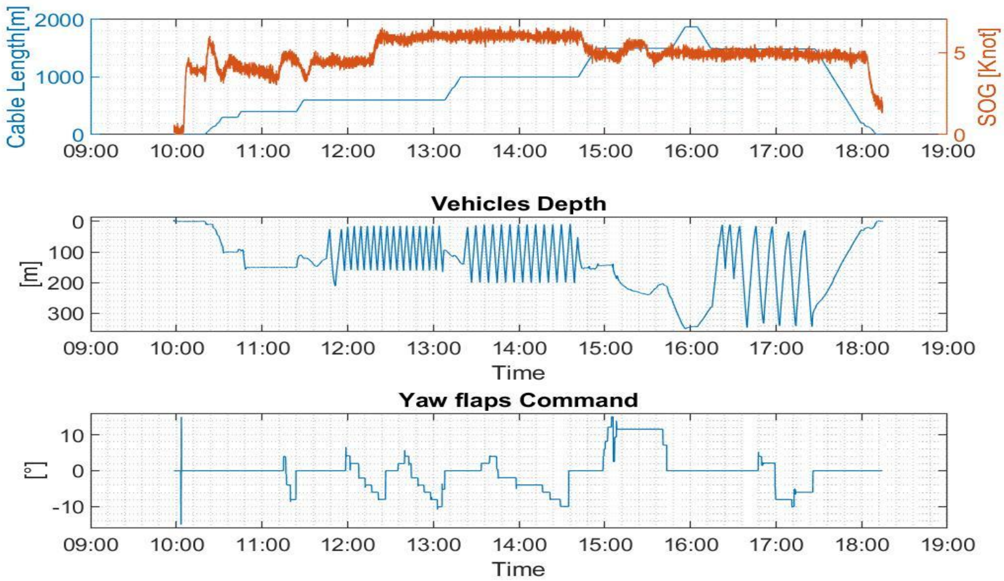


Figure 17: Main Characteristics of an operation. From this first view is possible for the reader to have an idea how was the deployment.

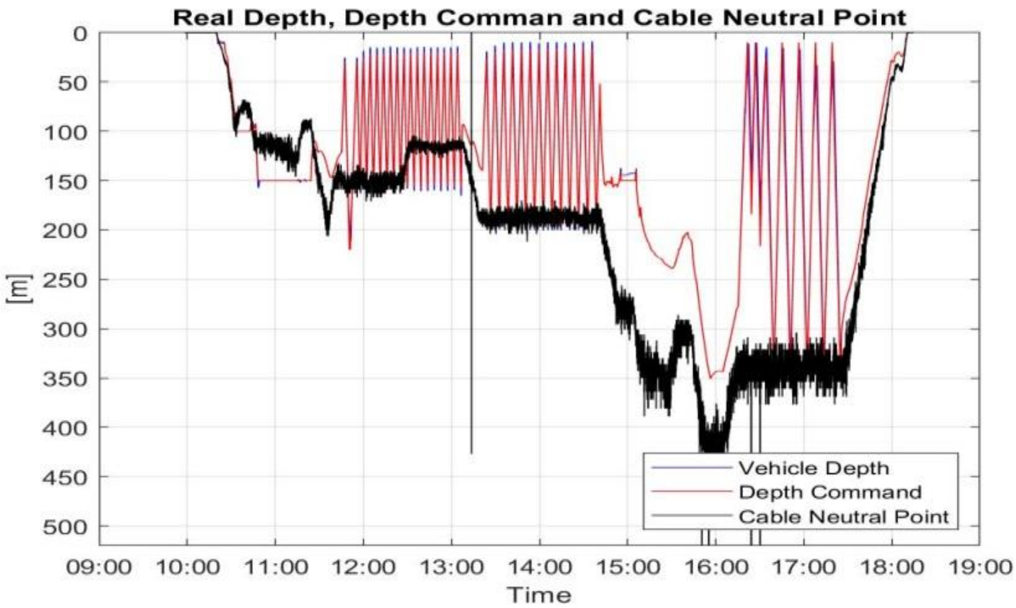


Figure 8: the second window of the report shows the depth of the vehicle (by the pressure sensor), the depth set in the control software and the cable neutral point of the system

[5] All the graphs presented here have the Intern as author.

The third section is dedicated to the positioning of the ship and the system. In deployments without GAPS only the ship track is shown.

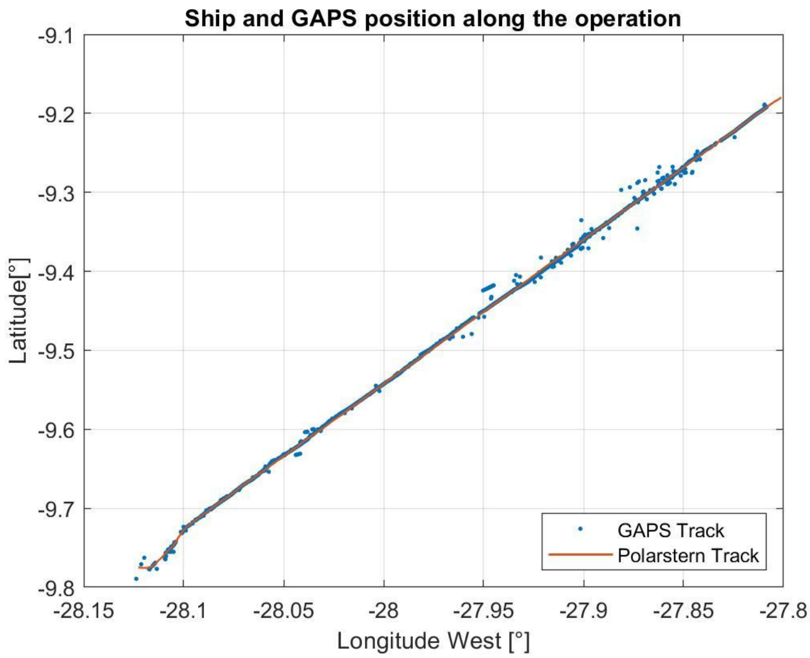


Figure 19: Ship track and vehicle's positioning given by the GAPS data

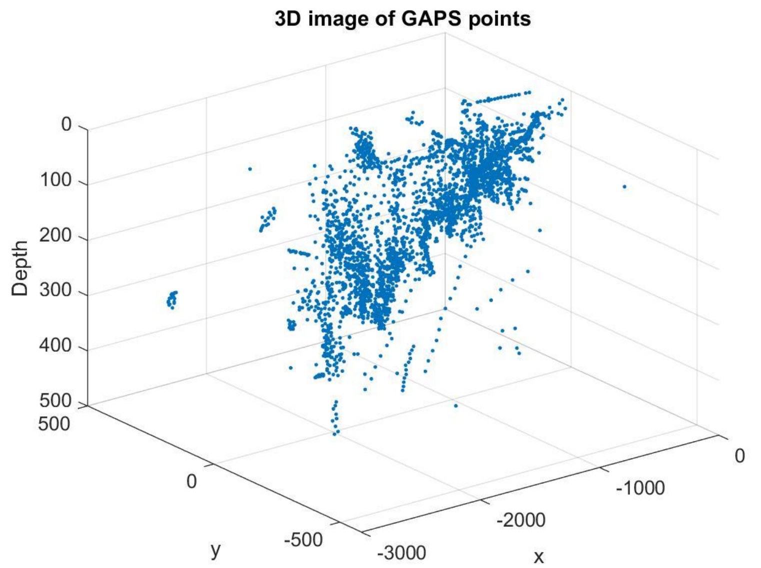


Figure 20: This is a 3D plot of the GAPS data; there is a script in the folder that shows the GAPS data evolution over time

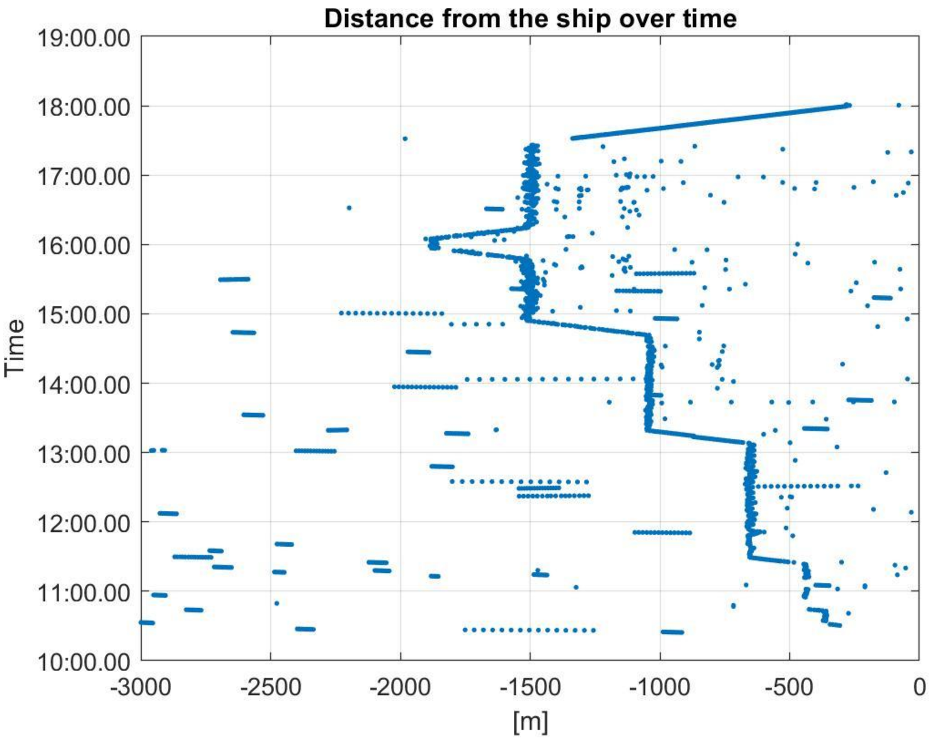


Figure 21: This plot shows the distance between *Polarstern* (0m) and the position of the GAPS. Note that this plot shows the data before any brushing

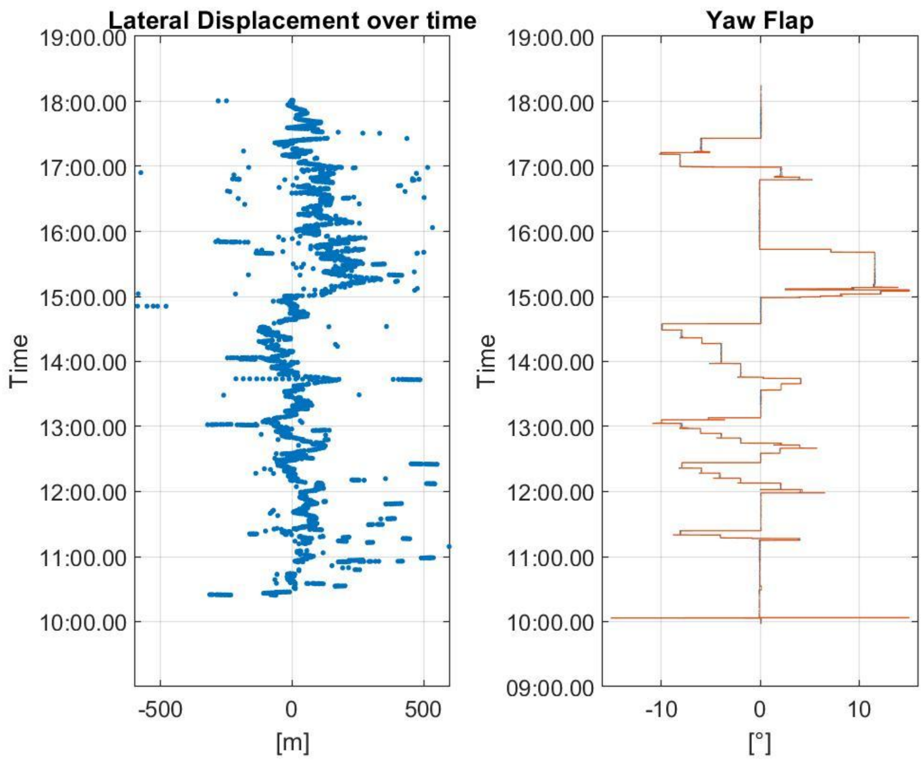


Figure 22: These Images are useful to compare the Lateral displacement over time (*Polarstern* is at 0m) with variations of the Yaw Flap

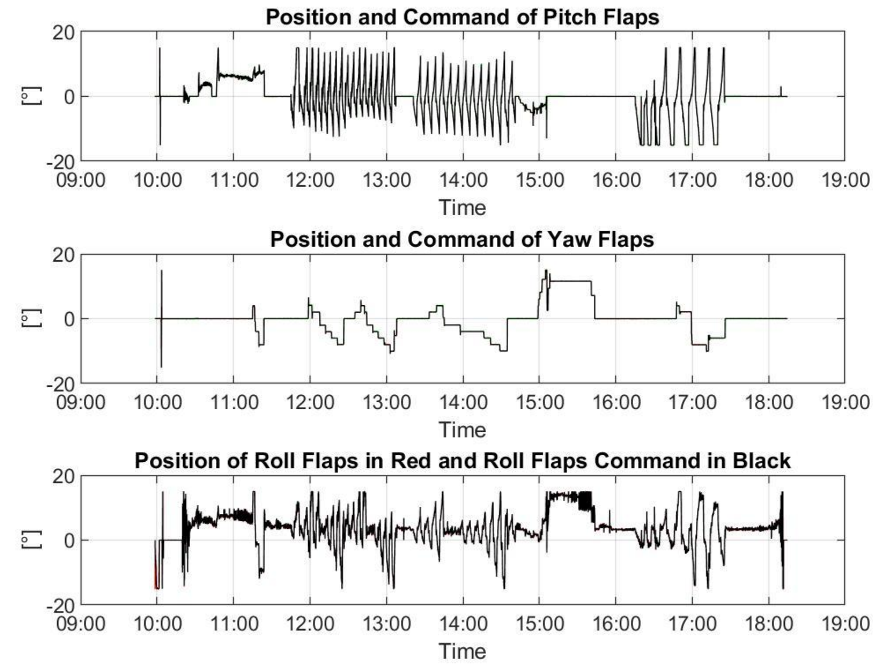


Figure 23: General view of Flaps behavior

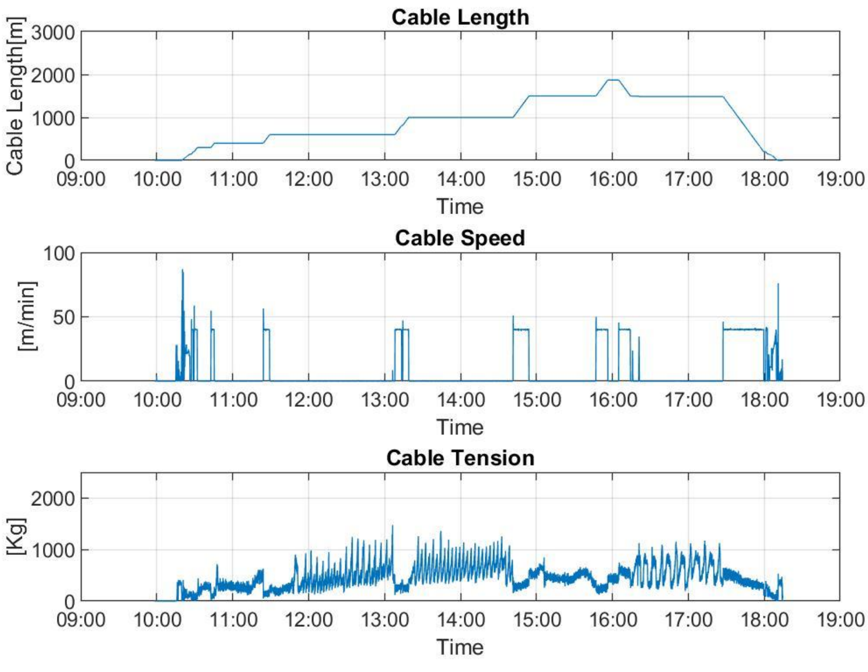


Figure 24: Winch operational parameters

Then the power system is represented.

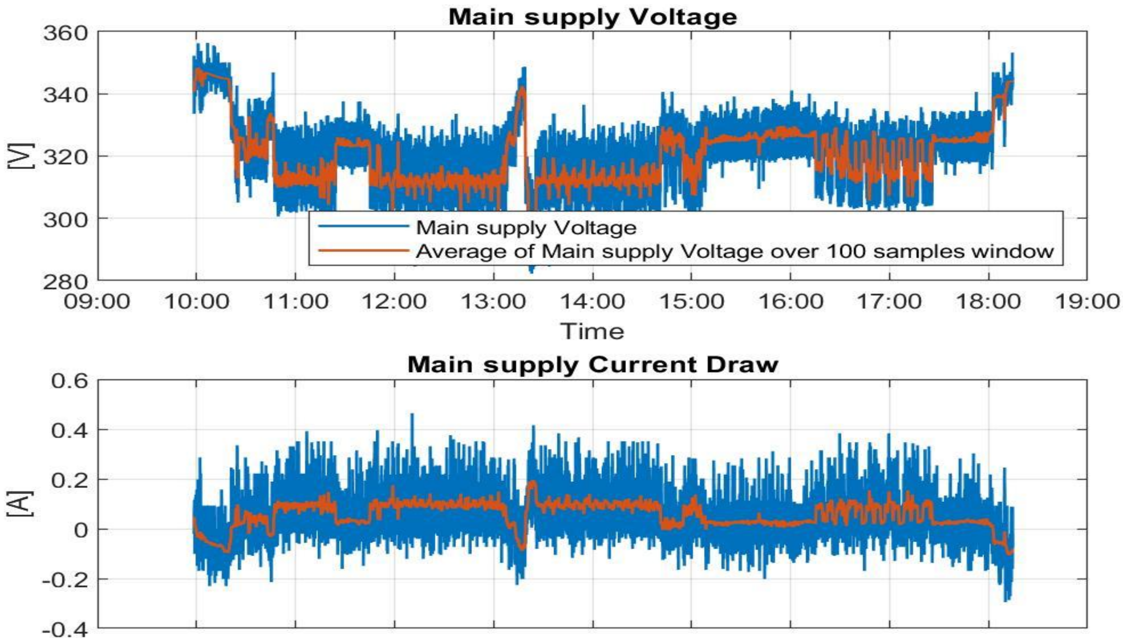


Figure 25: Main supply system

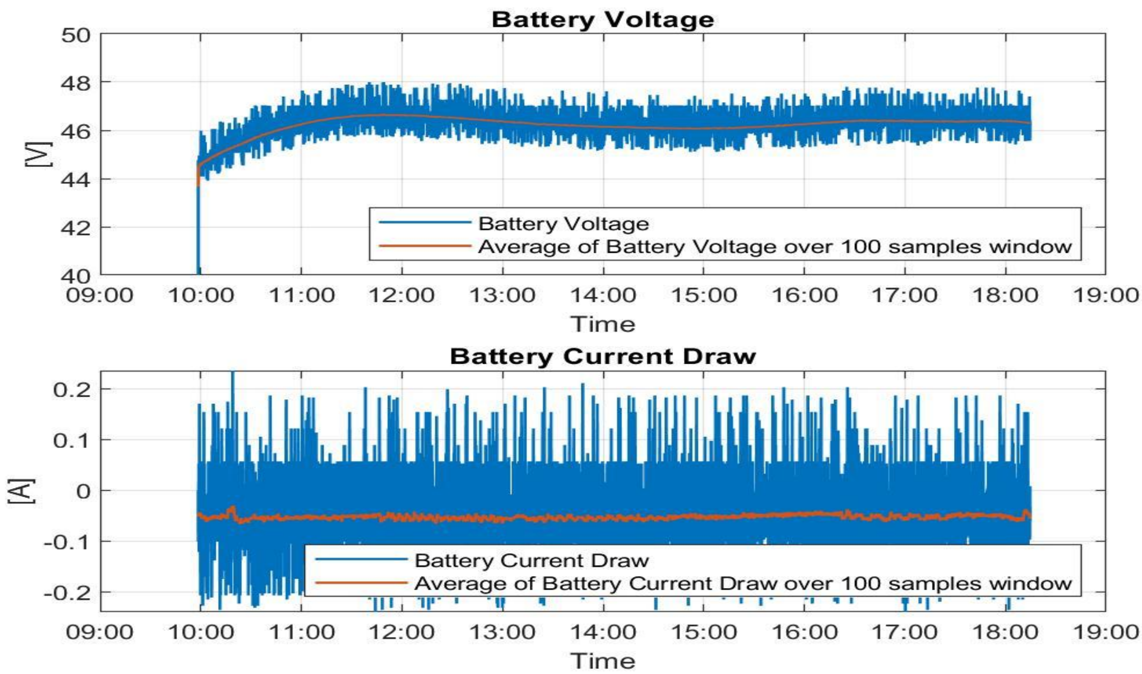


Figure 26: Battery voltage and current over time

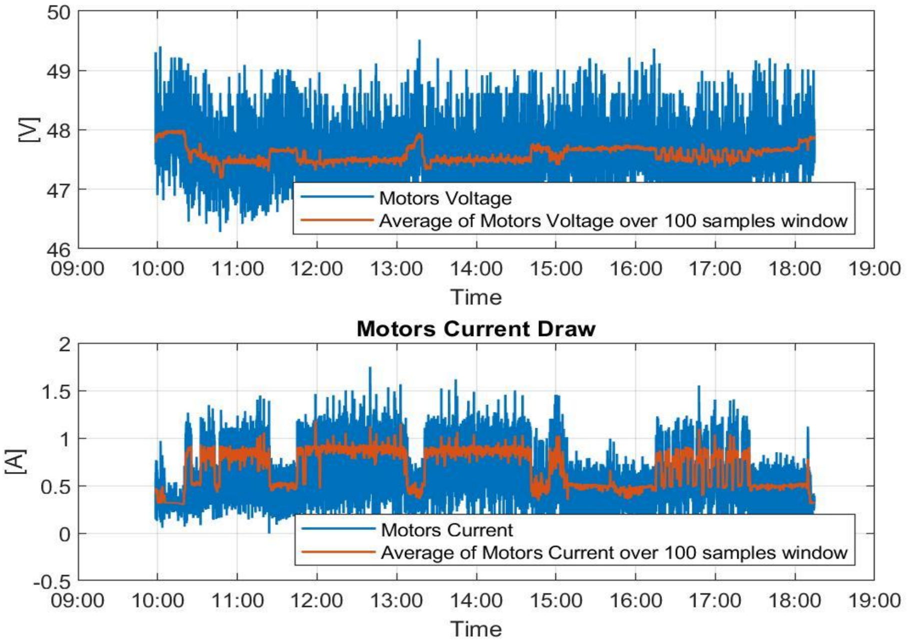


Figure 27: Motors Supply over time

Finally, the last plot that can be seen in the general report refers to the temperatures.

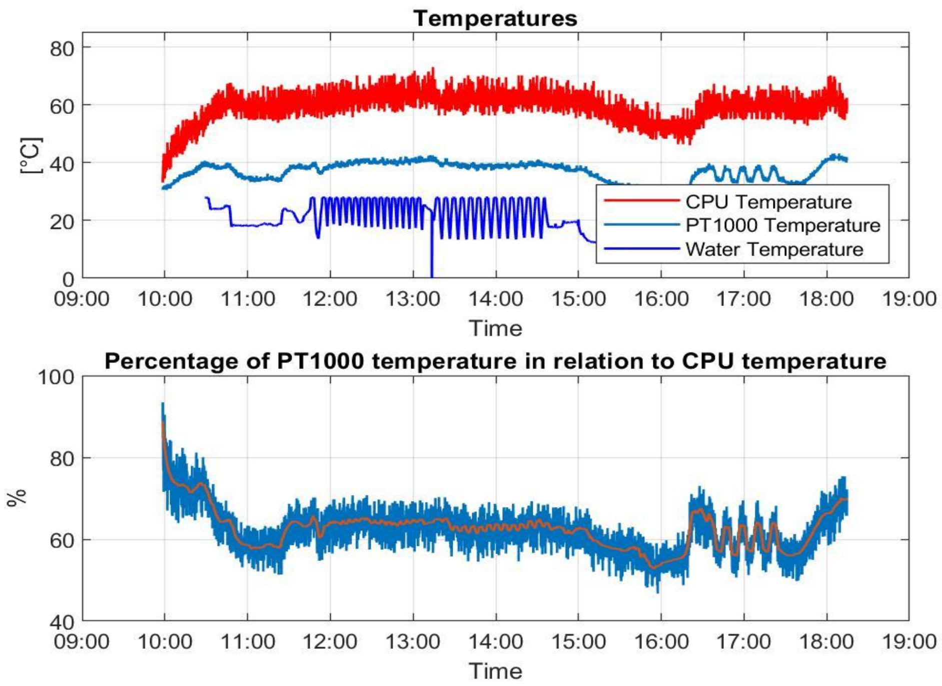


Figure 9: Temperatures of CPU, PT1000 and Water. The second plot shows a relation between the PT1000 and the CPU temperature

4.1.2. Temperature Analysis [6]

One of the parameters that can be monitored during Triaxus operations are the temperatures. From the system is possible to have access to the CPU temperature and of the PT1000 (the PT1000 temperature is the temperature of the air into the main bottle that surrounds the CPU). Besides these temperatures is also possible to monitor the water temperature collected by the CTD probes.

During two operations the system had the occurrence of high temperatures according to the PC control software, and in one of them in, the 0016_01 even the alarm of high CPU temperature range. The maximum temperature allowed for the CPU is 80 °C.

In order to investigate why the temperature was so high in these deployments, the intern started to work with the temperatures data. The two deployments (016 and 019) that showed up high temperatures are plotted below.

Source: the author

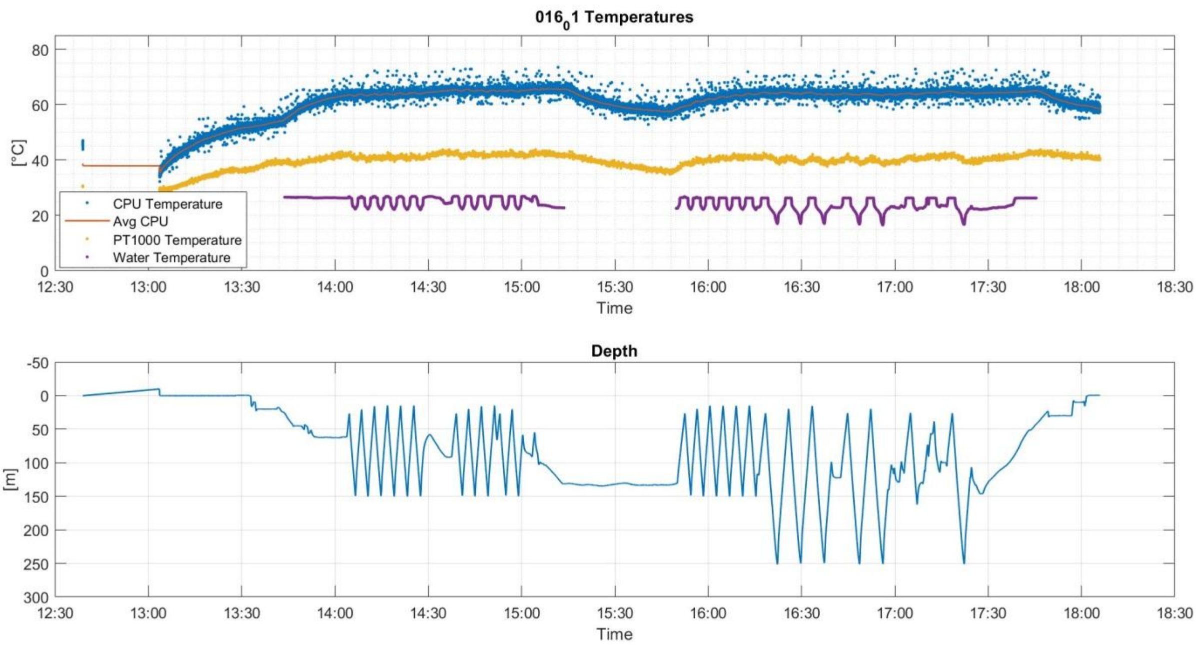


Figure 29: Deployment 016 in two graphs. The first one shows the temperatures of the Water, CPU and PT1000. And the second one is the depth of the vehicle

[6] Unfortunately for this section was not possible to correct the plot colors as Dr. Volker Strass requested. I tried several times to solve that issue but until this moment the only computer (here in Portugal) that I have access with Matlab® is not able to deal with the data for memory reasons that couldn't be solved in time.

Source: the author

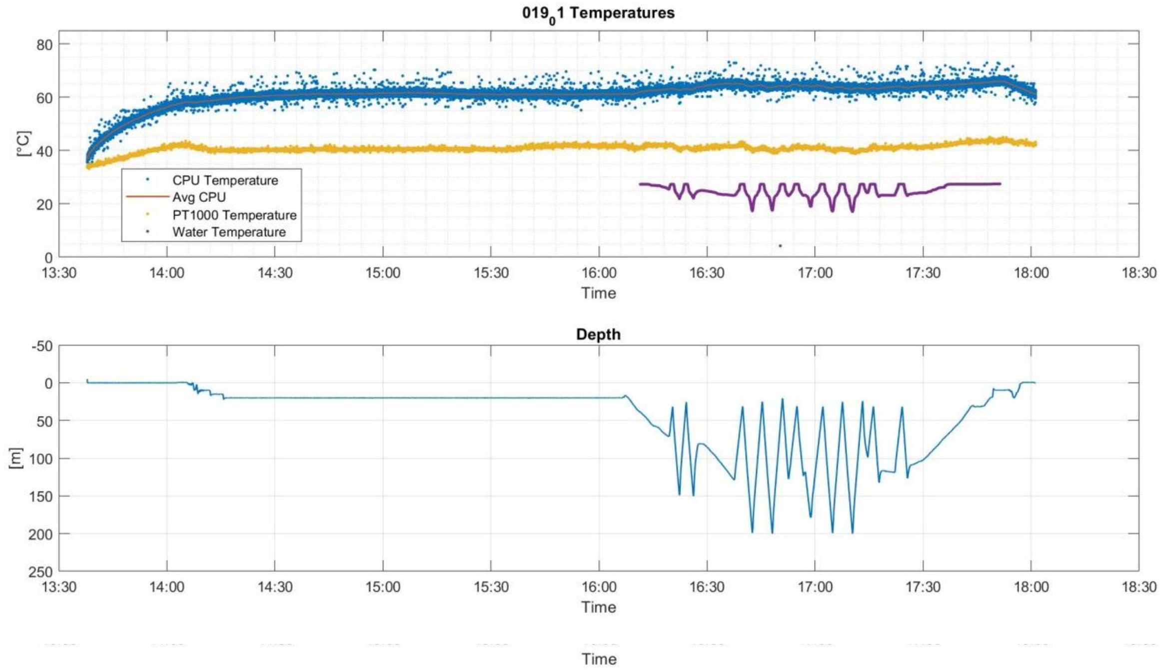


Figure 30: Deployment 019 in two graphs. The first one with the temperatures of the Water, CPU, and PT1000. And the second one is the depth of the vehicle

At first sight, a clear relation between depth and temperature can be seen. Due to the temperature changes according to the depth. However, looking closer to the temperatures plot of deployment 016 is possible to see that we have a very concentrated number of points making a clear line and some spikes surrounding this central line.

Source: the author

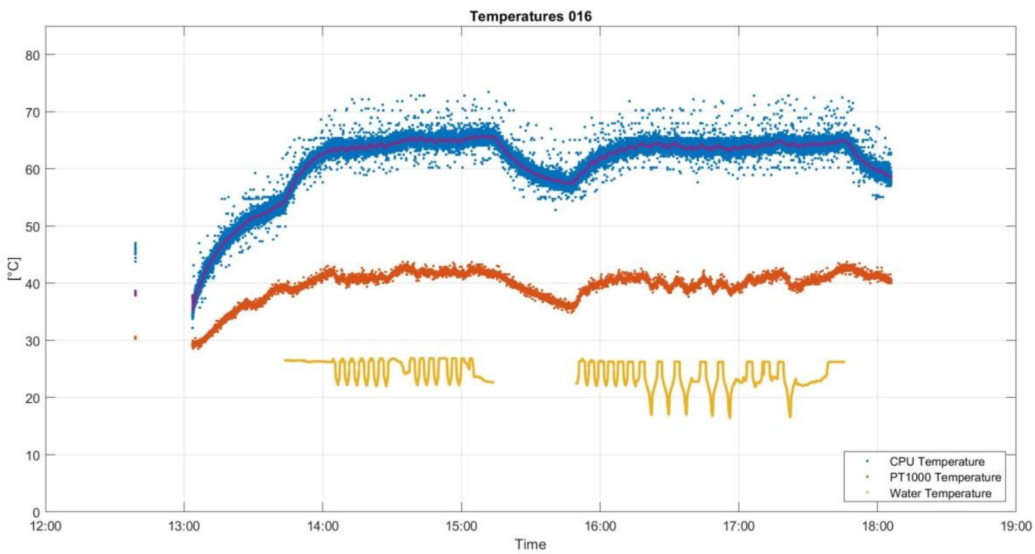


Figure 31: Deployment 016 temperatures

This pattern occurs not only in deployment 016 as also on 019 and as well can be seeing in all the deployments temperatures data. In figure 33 the purple central line is the average of each 100 samples of the CPU temperatures. The red dots in chart 33 are points of temperature higher than 70^{O}C.

Source: the author

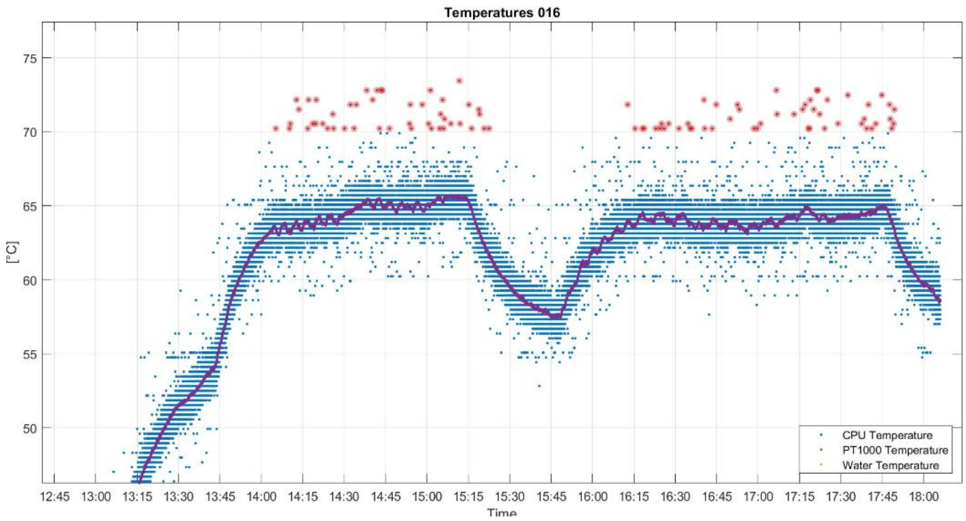


Figure 10: deployment 016 CPU temperature. All temperature points over 70ºC are marked in red

Looking deeper close, in figure 34, is possible to see a red dot between the time 15:11 and 15:12. This red dot made the high CPU temperature alarm to rang. It is the only sample above 72^{o}C during all the operation. From it is clearly visible that what we had was not an overheating, or at least not a constant high temperature enough to abort the mission ongoing.

Source: the author

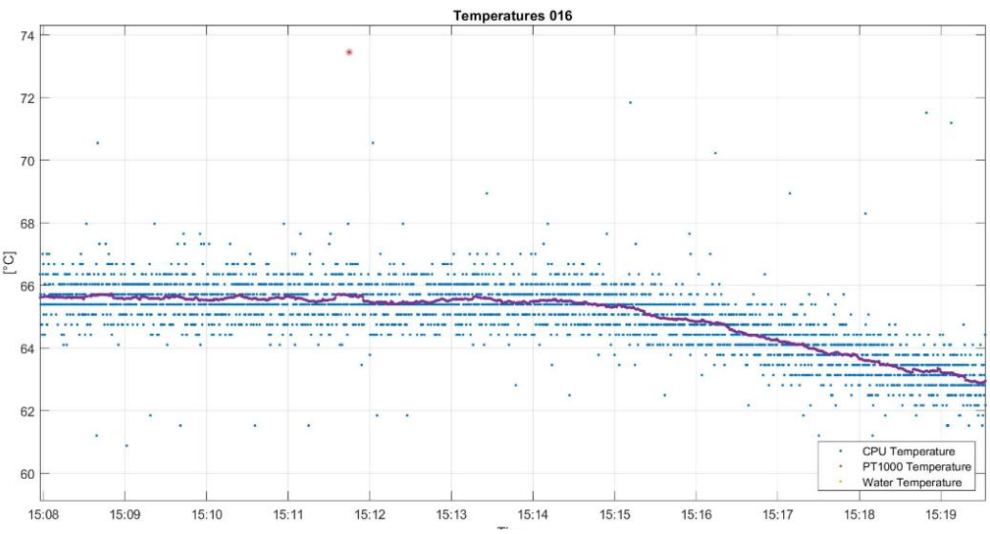


Figure 33: Overheating alarm point

This may be caused by reading error by the sensor as this highest point is about 9°C over the temperature average.

The next stage was to give for the temperature data a statistical overview over the **temperatures averages**. In the following figure are plotted the average of temperatures for each deployment.

Source: the author

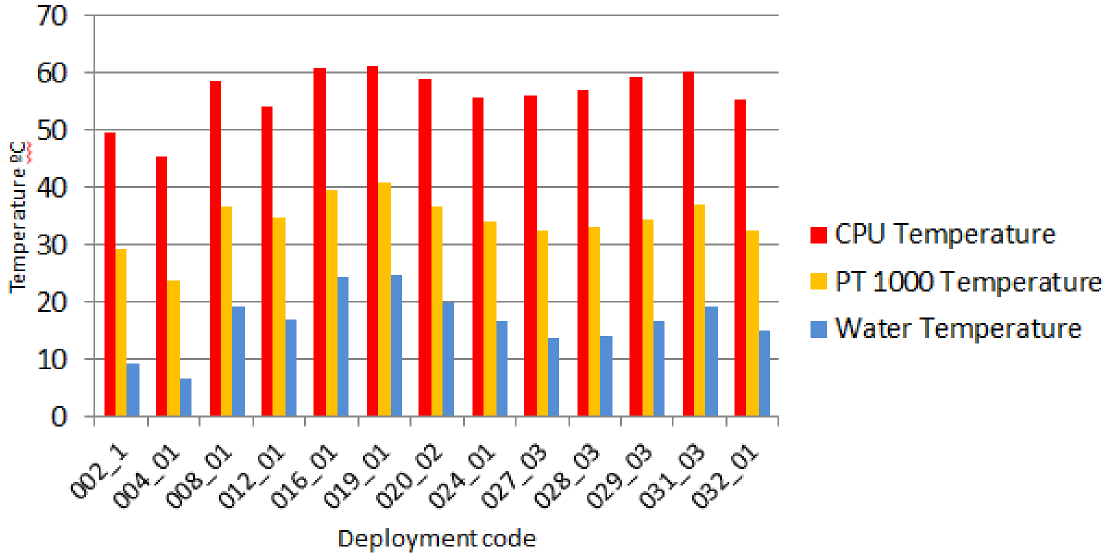


Figure 34: Temperatures average of each deployment of PS113

Looking to figure 35 we can clearly visualize the relationship between the seawater average temperature and CPU and PT1000 temperatures. From that is possible to see the influence that the region of operation (and thus environmental conditions) have over the system temperature.

In general, the average difference of temperature between the sea Water and the CPU is **39.29°C**. Therefore, as the temperature limit for the CPU is 80°C we can extrapolate and say that the Triaxus couldn't operate in water over **40.31°C** what of course is never going to happen. The average difference of temperature between the water temperature and PT 1000 is **17.42°C** and between the PT1000 and the CPU is around **22.11°C**.

4.1.2.1. Suggestion of future work for temperatures

Some interesting works to be developed with this part of the system that could help the operator to take decisions during the missions are:

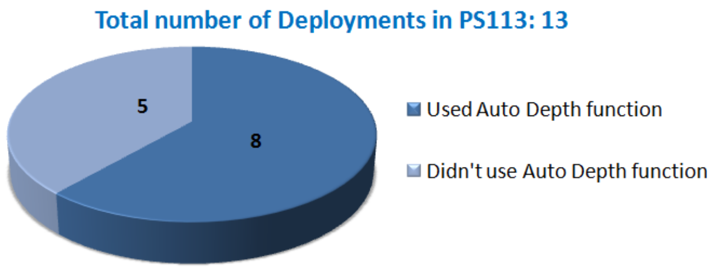
- Development of real-time temperatures reading and plot software;
- Analysis of the relation between each payload and energy consumption and thus as its effect in the system temperature.

4.1.3. Auto Depth Analysis

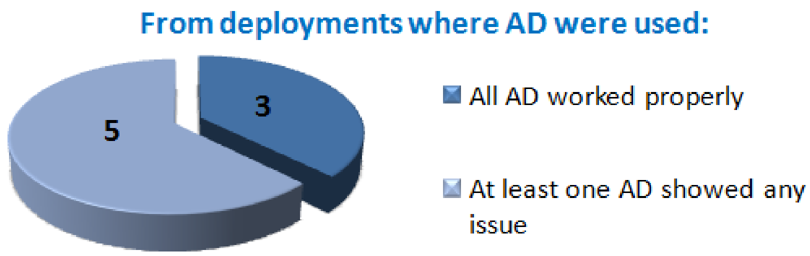
Along the expedition, the auto depth (AD) function was used several times to held Triaxus on a constant depth. Analyzing the operation procedures is possible to realize that during the initial operations the AD function worked seamlessly, however, for any reason the AD function did not respond well anymore during the latter operations, specifically in the last two operations. To try to understand for which reason (or at least under which circumstances) this function stopped to react as it should a detailed analysis of the operation conditions was developed.

Description of the issue: under some circumstances whenever the auto depth function was activated the vehicle did not respond as it should, not going to the envisaged depths. In some cases, when the vehicle was changing from one depth to another it used to start to change the depths, however, it did not stop when it should and kept moving towards the sea surface or to deeper depths. In other cases, the vehicle simply went to the wrong depths.

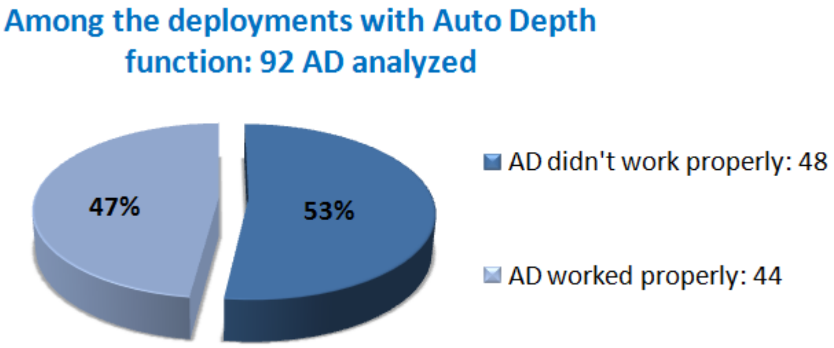
To try to understand why and when it was happening all the data of the operational parameters were analyzed. During the thirteen times that Triaxus was deployed in the sea, in eight the AD function was used.



And from these eight deployments, in five of them, the AD function failed at least once.



And among these five deployments, the auto depth function was activated 92 times. As we can see in the figure below, in 48 times the function did not work properly and in the other 44 times, the vehicle reacted as it should.



At first sight can be seem that AD barely worked during the expedition, however, is important to make clear that from the 48 times where the AD did not work properly, 45 occurred along the last two deployments, when the team was purposely activating the AD function to try to understand why it was not working. It can be clearly seem in the following graph.

Source: the author

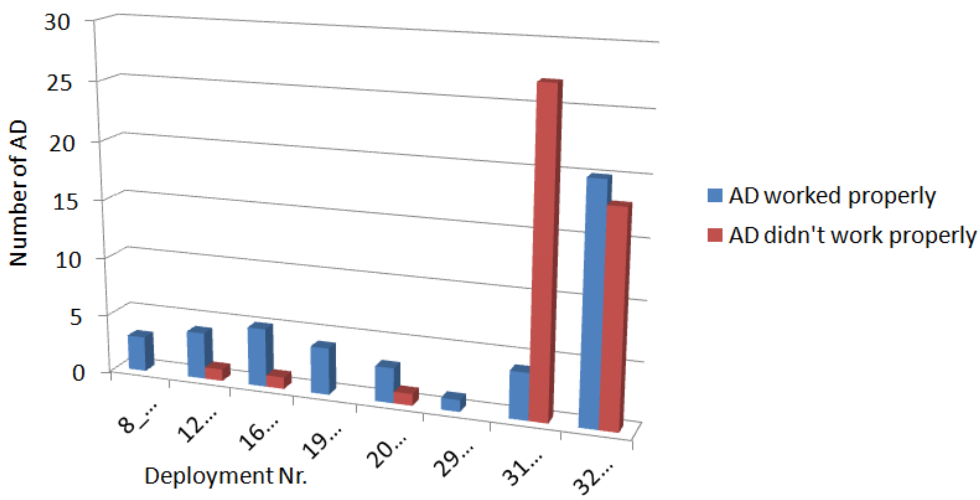


Figure 35: Successful and failure Auto Depths operations in numbers

With the numbers shown in the previous graphs, we know that in the last two deployments we had something that could have been interfering in the performance of the auto depth function. The next step was to compare the operational conditions between the deployments where the AD worked properly and where it did not. An exhaustive comparison and analysis work was developed with the aim to understand the relations between the suite of parameters and their effect on the AD function.

Neither parameter showed considerable effects over the AD as the relation between the data from the depth sensor and the calculated cable neutral point position.

To illustrate the behavior of the cable neutral point, vehicle's depth and the depth set by the command given in the software, we can have a look in the next graph.

In this graph is possible to see the depths (of the three depth parameters: software given, real vehicle's depth and cable neutral point position) along time. This frame is from June 1st, along deployment 31_03.

Source: the author

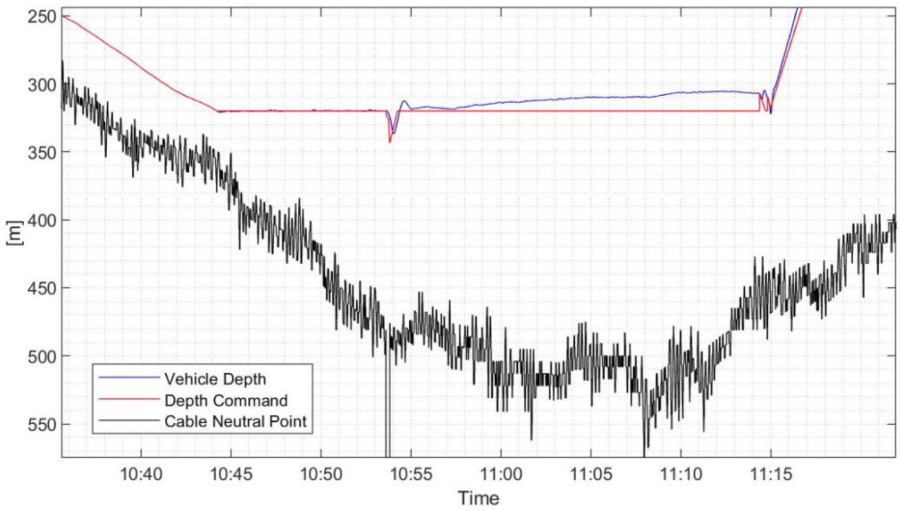


Figure 36: Data from the depth sensor (Vehicle's depth), software depth command and cable neutral point along deployment 031_03

The chart above is interesting because on it is possible to visualize both situations: when the Auto Depth function was working properly and when not. Looking to the left part of the chart on the x label, between the time 10:35 and 10:53 the AD function was working properly, as it shows that the vehicle's depth (blue line) and software depth command (red) are overlapping as if it were the same row, that means that the vehicle's depth is exactly the one that was set on the software, what is paramount for the operation. However, after a quick attempt to change the vehicle´s depth, it stopped to work as it should and the vehicle's depth and the depth set on the software were different, crafting meaningful errors.

Discrepancies between the AD and vehicle's depth were present along many circumstances and heightened as the difference with the cable neutral point increased. To try to understand why and when it was happening, the intern developed some scripts on *matlab®* to visualize under which operational parameters and (or) due which disturbances these issues were happening.

Miscellaneous approaches were used to correlate the conditions of operation and its effects on the AD function. The charts of next page were plotted to better illustrate how the difference between the cable neutral point and the depth sensor affects the AD performance.

The chart of figure 37 gives an overview of the operation 031_03. From this chart is clear how during this deployment the AD did not work properly. Charts from figure 38 and 39 show the difference between the Cable Neutral point and Depth sensor and the difference between the depth sensor readings and the depth command set in the control software (which can be seen as the error between the depth command and actual depth of the vehicle) respectively.

Source: the author

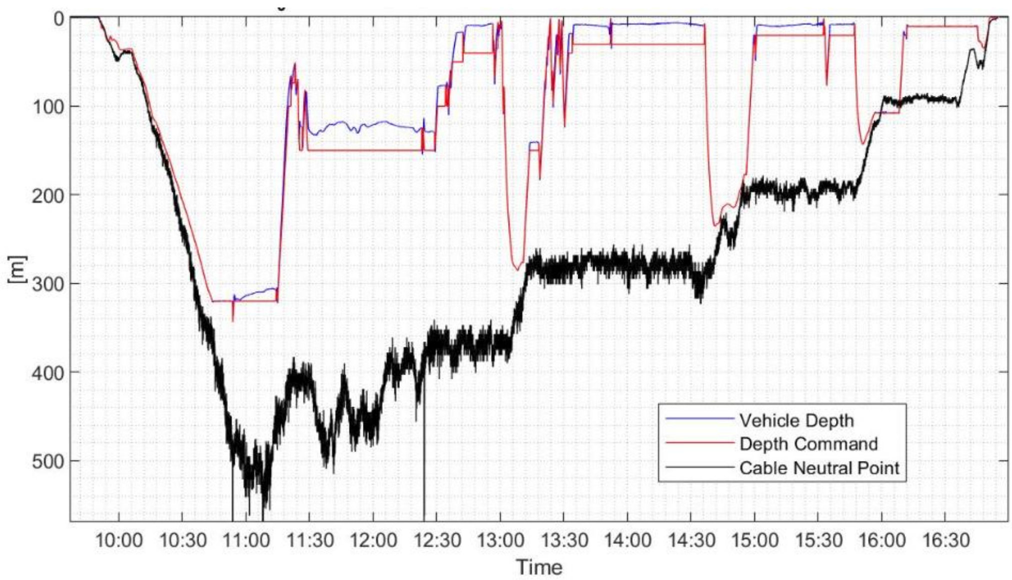


Figure 37: An overview of deployment 031_03

Source: the author

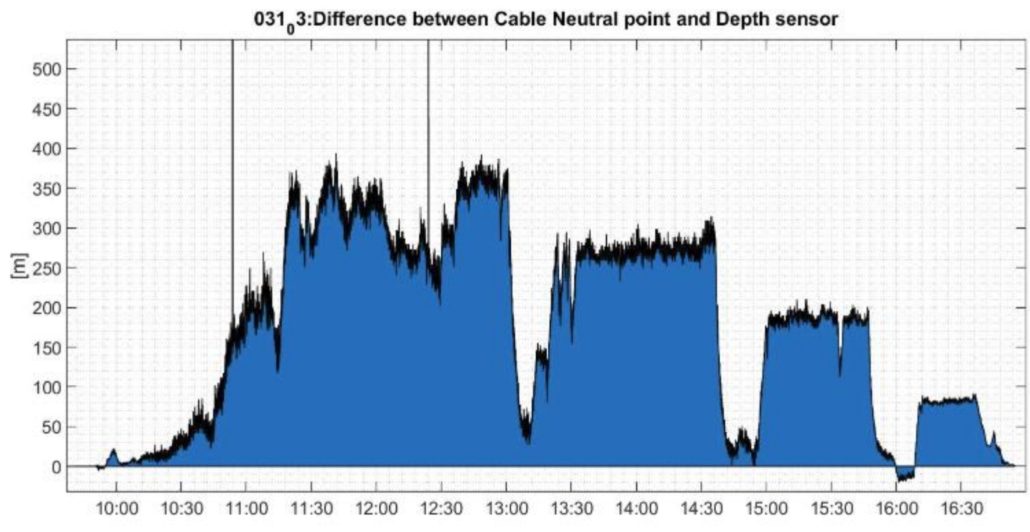


Figure 38: Difference between cable neutral point and depth sensor readings. Note that the blue area effect is only present to highlight the difference between both parameters.

Source: the author

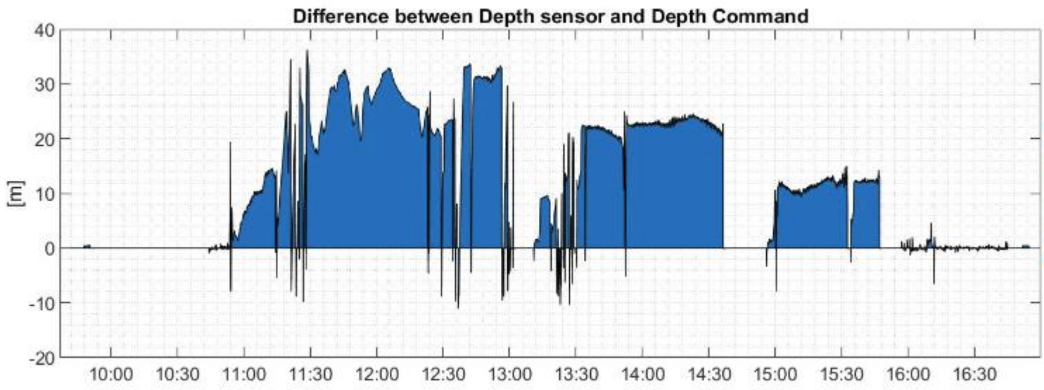


Figure 39: the difference between depth sensor reading and the depth set on the control software can be considered the error between both. Note that the blue area effect is only present to highlight the difference between both parameters.

After an exhaustive work, where all deployments were analyzed, a curious pattern appeared. Whenever the difference between the actual depth of the vehicle (pressure sensor) and the calculated cable neutral point surpassed 100 m the chances of the auto depth function to exhibit a faulty performance were extremely high.

The following chart gives an overview of how that difference is associated with the assertiveness of the AD function. The Y label shows the percentage of successful (or faulty) AD attempts, whereas, the X label represents the range of various differences between the cable neutral point and vehicle's depth and in the parenthesis the total number of AD attempts.

Source: the author

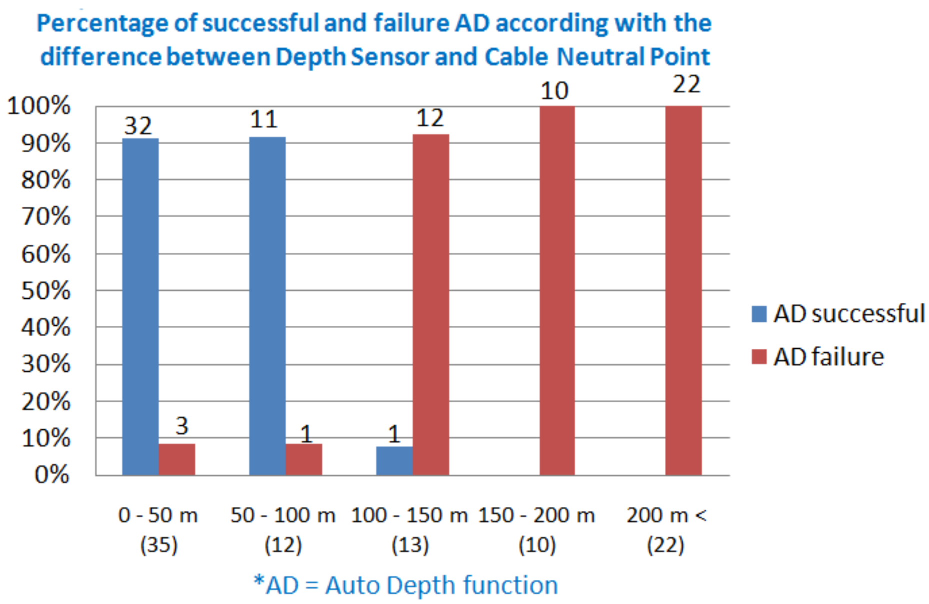


Figure 40: successful and failure AD in percentage according with the differences.

According to the chart above, is clearly visible that the AD works much better whenever the difference is up to 100 meters. From zero to 100 meters of difference the probability of AD to work properly is around 92%. However, in operational circumstances where the difference between the depth sensor (vehicle's depth) and cable neutral point is higher than 100 meters the successful rate drops abruptly to 8% to the range from 100 m to 150 m and for a difference higher than 150 m the data recorded a rate of 100% of failure of the AD function.

Curiously, the AD function failures are not proportionally related to the vehicle's depth and cable neutral point (some proportional relations between both did not indicate any relation to the faulty behavior). Instead of that, only the modulus of depth differences apparently presented effect over the system behavior.

Once identified under which circumstances the issue involving the AD occurs (**When**), the student tried to understand **why** it was occurring. Trying to understand which physical components are involved in these specific situations.

Observing the operation charts, as in figure 37, we can see another curious pattern: the blue line (vehicle's depth) is always above the red line (depth set on the control software) and also above the black line (cable neutral point position). It means the vehicle was always "flying" above the determined depth on the software.

Physically, seems to be no reason that for whenever the cable neutral point is much deeper (>100m) than the vehicle, the system is not able to reach the desired depth, flying above the set point. As the vehicle has slightly positive buoyancy most of the system weight is due to the tether. Thereby, as deeper the cable neutral point is, heavier is the system and should be harder for the vehicle to achieve the desired depth. However, as the weight arises from the gravitational force, it acts downwards and the vehicle should present difficulties to go upwards to reach the right position. Consequently, on chart of figure 37 the blue line (vehicle's position) should be bellow the red line (depth set on the software) and then we could deduce that what bounds the vehicle to reach the desired depth would be the flaps disability to generate enough lift force in order to compensate the cable weight. However, instead of that, the system presented a curious behavior with the vehicle always holding its position above the desired position, what implies that the issue is not due to the tether weight.

As the cable neutral point results, essentially, from the combination of the ship speed and cable length [4] I tried to find a relation between these set parameters and, consequently, the cable neutral point condition, however, was not possible to directly relate such parameters with the Auto Depth failures.

4.1.3.1. Auto depth failures: Conclusion and suggestion for future work

As briefly described in the previous topic, it was not possible to determine exactly why the auto depth function was not working properly. However, was possible to notice when it was occurring. Apparently, seems the AD issue is caused (maybe) for a bug in the control software. Although, as it is not possible to check the software algorithms, this is only one hypothesis.

As a suggestion for future expeditions follows:

- Firstly, as obvious, is to get in touch with the manufacturer *MacArtney* and report the situation to find out the most suitable solution;
- If not possible to set right the AD issue until the next operation a palliative solution could be to configure the *Triaxus* PC dashboard to show in real-time the cable neutral point position. Thus, would be possible for the pilot to try to avoid situations when the difference between the cable neutral point and vehicle depth would be higher than 100 meters.

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