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The Expedition PS108 of the Research Vessel POLARSTERN to the Fram Strait and the AWI-HAUSGARTEN in 2017

Edited by

Frank Wenzhöfer

with contributions of the participants

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Titel: Bergung des AWI Tiefsee-Crawlers TRAMPER nach Beendigung seines 1-Jahres Einsatz am arktischen Meeresboden. (Foto: E.Horvath).

Cover: Recovery of the AWI deep sea crawler TRAMPER after one year mission at the Arctic seafloor (Photo: E.Horvath).

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PS108

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Tromsø - Tromsø

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Contents

1. ZUSAMMENFASSUNG UND FAHRTVERLAUF

Frank Wenzhöfer AWI

Die Forschungsreise ROXES-DM (PS108) der FS *Polarstern* diente vornehmlich zwei Themen: (I) Verifikation der Einsatzmöglichkeiten neuer, innovativer Technologien, die im Rahmen der HGF Allianz ROBEX (Robotische Exploration unter Extrembedingungen) entwickelt wurde, für die Exploration extremer Lebensräume und der kontinuierlichen Untersuchung in der Tiefsee sowie (II) Durchführung von Messungen und Probennahme an den Tiefsee-Experimenten am LTER Observatorium HAUSGARTEN mit Hilfe des ROV KIEL 6000 (Geomar). *Polarstern* operierte während der Reise in zwei Arbeitsgebieten (Abb. 1.1), der östlichen Fram Strasse am Tiefseeobservatorium HAUSGARTEN (Abb. 1.2) und in der Gashydrat Stabilitätszone vor Spitzbergen (Abb. 1.3). Die Fähigkeit wichtige Fragen zur Veränderung unserer Ozeane zu untersuchen, ist grundlegend limitiert durch den Mangel an Schlüsseltechnologien, die uns erlauben, *in-situ* Experimente durchzuführen, gezielt Proben zu entnehmen sowie langzeitstabile Sensormessungen im Ozean durchzuführen. Das Ziel der *Polarstern* Expedition war es, neue und innovative Unterwasser-Technologien, die im Rahmen der HGF Allianz ROBEX entwickelt und gebaut wurden, in der Tiefsee einzusetzen, um biogeochemische Prozesse im Ozean besser verstehen zu können. Hierzu zählen drei unterschiedliche benthische Crawler Systeme, jeder entwickelt für spezielle wissenschaftliche Fragestellungen, ein Glider, unbemannte Flugsysteme (Unmanned Aerial Vehicle, UAV) die den Einsatz des AUVs unterstützen sowie Sensorik für Langzeitmessung von Sauerstoffprofilen und ein Unterwasser-Massenspektrometer. Dies demonstriert und verifiziert zum einen die Interoperabilität von robotischer Technologien für den Einsatz in extremen Lebensräumen und zur kontinuierlichen Meeresbeobachtung. Darüber hinaus tragen die Messungen direkt zu Ökosystemuntersuchungen in der Arktis bei. Hierbei wurden arktische Ökosysteme untersucht, die stark vom Klimawandel beeinflusst sind, wie z.B. Gashydrate in arktischen Schelfsedimenten und benthische Tiefseegemeinschaften. Im Gebiet der Gashydrat Stabilität Zone (GHSZ) wurden die Gaskonzentrationen in der Wassersäule auf unterschiedlichen räumlichen und zeitlichen Skalen quantifiziert. Arbeiten am HAUSGARTEN - Tiefseeobservatorium dienten der Untersuchungen des Kohlenstoff- und Nährstoffflusses, sowie der Verknüpfung, Zusammensetzung und Struktur von benthischen und pelagischen Lebensgemeinschaften auf unterschiedlichen zeitlichen und räumlichen Skalen (Beiträge zum Forschungsprogramm PACES-II, Polar regions And Coasts in the changing Earth System). Die Expedition diente darüber hinaus dazu, um weitere Installationen im Rahmen der HGF Infrastrukturmaßnahme FRAM (FRontiers in Arctic marine Monitoring) vorzunehmen. Die gesamten Arbeiten werden dabei durch das ROV KIEL 6000 (Geomar) unterstützt.

Am Dienstag, den 22. August um 19 Uhr startete *Polarstern* von Tromsø aus mit ungewöhnlicher Fracht in Richtung Spitzbergen. Ungewöhnlich zum einen, dass von den etwa 40 Wissenschaftlern, Ingenieuren und Technikern erstmals 10 „Raumfahrer“ mit an Bord waren und ungewöhnlich waren auch die neuen robotischen Systeme, die in Zukunft die Erforschung der Tiefsee voran bringen sollen. Entwickelt wurden diese robotischen Systeme seit 2012 in der Helmholtz Allianz ROBEX, in der 120 Wissenschaftler aus insgesamt 16 Institutionen der Tiefsee- und Weltraumforschung zusammenarbeiteten.

Am 24. August erreichten wir unser Forschungsgebiet und das Arbeitsprogramm startete mit dem Einsatz zweier Freifallgeräte zur Messung der Sauerstoffzehrung im Meeresboden. Diese Messungen sind Teil der Zeitserie am Tiefseeobservatorium HAUSGARTEN und werden seit mehreren Jahren regelmäßig durchgeführt. In der Nacht wurde der CATAMARAN eingesetzt, ein System das an der Seite des Schiffs ein Netz über die Meeresoberfläche zieht, um so Müll und Mikroplastik einzusammeln.

Am Morgen des 25. August wurde erstmals das ROV KIEL 6000 des GEOMAR an der Stelle ins Wasser gebracht, an der vor über einem Jahr (während PS99.2) der Crawler TRAMPER gestartet ist. Während seines ein-jährigen Einsatzes führte er wöchentlich Messungen der Sauerstoffverteilung im Meeresboden durch. Die Wettersituation ließ eine Bergung aber nicht zu, da der Seegang zu hoch war für den notwendigen Einsatz des Schlauchboots.

Mit dem geschleppten Video und Foto-System OFOS wurde ein Tauchgang an der tiefsten Stelle der Arktis (5.500 m Wassertiefe), dem Molly Deep, durchgeführt. Der letzte Einsatz hier lag bereits 20 Jahre zurück. Die neuen Fotos zeigten ein durchaus reges Leben in großer Tiefe mit unzähligen kleinen Seegurken und Seeanemonen. Außerdem war dort viel Holz und leider auch sehr viel mehr Müll zu sehen. Die neuen Daten können jetzt mit denen aus 1997 verglichen werden und liefern so vielleicht Hinweise darauf, wie sich das Ökosystem verändert hat.

Der zweite ROV-Tauchgang widmete sich einem biologischen Langzeit- Experiment, welches im letzten Jahr ausgebracht wurde. Sogenannte „Dropstones", Steine unterschiedlichster Größe, die mit dem Meereis verfrachtet werden und Hartsubstrate darstellen, die von einer Vielzahl festsitzender Organismen besiedelt werden können und somit einen erheblichen Einfluss auf die Biodiversität der Tiefsee haben. Bislang ist nicht bekannt, wie schnell die Lebewelt des Tiefseebodens auf den Eintrag neuer Dropstones am Meeresboden reagiert. Während des ROV-Tauchgangs wurden Sedimentkerne im Umfeld der Strukturen genommen, die uns Auskunft über die Organismen- und Nahrungsverteilung nach einem Jahr geben sollen.

In der Nacht vom 26. August bis zum Nachmittag des 27. August stand die Untersuchung der Durchmischung von arktischem und atlantischem Wasser im Fokus der Arbeiten. Der Grenzbereich dieser Wassermassen hat großen Einfluss auf oberflächennahe biologische Prozesse. Mit schiffsbasierten Sensoren wurden mehrere Transekte abgefahren, um die Mischungszone zu finden. In diesem Bereich wurde anschließend das autonome Unterwasser-Fahrzeug (AUV) PAUL eingesetzt. Mit seinen Instrumenten konnten sowohl die horizontalen als auch die vertikalen Strömungs- und Durchmischungsprozesse detailliert untersucht werden.

Am Nachmittag des 27. August konnte TRAMPER, nach einem Jahr auf Mission am Meeresboden, wieder an Bord holt werden. Eine erste Sichtung des Systems zeigte, dass er bestens funktioniert hat, bis seine rechte Kette stillstand. Er hat 24 Messungen durchgeführt, die etwa einen Zeitraum von einem halben Jahr abdecken und somit neue Erkenntnisse über die zeitliche Veränderung der Sauerstoffverteilung im Meeresboden liefern.

Während zahlreicher Nächte und frühen Morgenstunden wurde mehrmals das Unterwasser-Membran-Einlass-Massenspektrometer (UW-MIMS) zur Detektion von gelösten Gasen in der Gashydrat Stabilitätszone (GHSZ) vor Spitzbergen eingesetzt. In dieser Region kommt es entlang eines 25 km langen Abschnitts am oberen Rand der GHSZ in ca. 400 m Wassertiefe zu einer starken Freisetzung von Methan aus dem Meeresboden in die Wassersäule. In Echolot Aufzeichnungen konnte diese Gasfreisetzung detektiert und kartiert werden.

Das UW-MIMS wurde während dieser Expedition erstmals unter erschwerten Freiwasser- und Schiffsbedingungen eingesetzt. Nach anfänglichen Schwierigkeiten konnte während des dritten Einsatzes des UW-MIMS das Methansignal simultan zu anderen gelösten Gasen erfolgreich aufgezeichnet werden.

Eine neue Form eines Unterwassergleiters, der MAPPA, wurde während der *Polarstern* Fahrt erstmalig vom Schiff aus zum Einsatz gebracht. Nach erfolgreichen Tests führte der Gleiter, dem ein Deltaflügler-Design zugrunde liegt, seinen ersten einstündigen Tauchgang bis in 105 m Wassertiefe durch.

Während unserer Arbeiten an der Eisgrenze bei 80°N absolvierte das AUV PAUL einen sehr erfolgreichen 3-stündigen Tauchgang, ohne Kontakt zur Kontrollstation auf dem Schiff, unter das Eis und zurück. Die gewonnenen Daten liefern neue Erkenntnisse über die den Grenzbereich Meereis – Ozean.

Am Abend des 31. August wurde an der zentralen Hausgarten Station ein weiterer ROV-Tauchgang durchgeführt, um ein Langzeit-Experiment zur Besiedlung in der Tiefsee zu bergen. Das Experiment bestand aus einem Gestell und 46 angebundene Platten aus festen Materialen, wie Ton und Plastik. Das 1999 begonnene Experiment sollte zeigen, wie sich - über die Zeit - Tiefseeorgansimen auf solchen festen Substraten ansiedeln und entwickeln.

Der Bewuchs auf den Platten und dem Gestell zeigte insgesamt 4 Arten von Foraminifera (einzellige Lebewesen) und etwa 10 Arten von Tieren. Die neuen Proben ermöglichen nun eine Analyse der Wachstumsgeschwindigkeit von Tiefseetieren sowie die Entwicklung von Lebensgemeinschaften in der Arktis.

Während zahlreicher Nächte nutzen wir das geschleppte OFOS System um fünf Transekte des Meeresbodens im Molloy Tief, Kongsfjord Canyon, Hyes Tief und der nördlichsten Hausgarten Station (N5) durchzuführen. Die Analyse der Fotos ermöglicht es die Megafauna Zusammensetzung dieser unterschiedlichen Meeresbodenregionen zu vergleichen.

Am Abend des 04. September startete der zweite Einsatz des neuen robotischen System MANSIO-VIATOR. Dieses System, aus dem Tiefseecrawler VIATOR und einem fixen Lander, MANSIO, wurde erstmals in einer Tiefe von 1.276 m am Vestnessa Ridge westlich von Svalbard getestet. Nach einer Erkundung mit dem ROV KIEL 6000 konnte das System punktgenau abgesetzt werden. Nach der programmierten Warteperiode startete VIATOR selbstständig seine Mission. Beim Herausfahren traten zwar Probleme am Antriebsstrang auf, die aber nach einem Missionsabbruch mittels einer akustischen Verbindung (USBL) teilweise behoben werden konnten. Am Endes dieses Einsatzes konnte das komplizierte Docken, d.h. der Prozess der Rückfahrt des Crawlers in den Lander, durchgeführt werden.

Am 3. September wurde Tramper auf seine zweite einjährige Mission geschickt. Die Bergung soll dann im nächsten Jahr während der Expedition MSM77 erfolgen. Ein zweiter Crawler - NOMAD -, der ebenfalls saisonale Variationen der biogeochemischen Prozesse am Meeresboden erfassen soll, wurde erfolgreich getestet. Neben der Messung der Sauerstoffzehrung, soll NOMAD zusätzlich Daten zur räumlichen Verteilung des frisch absinkenden organischen Materials liefern.

Am Nachmittag des 06. September beendeten wir unsere Forschungsarbeiten und machen uns auf den Rückweg. Die Fahrt endete am 9. September in Tromsø. Die Fahrt war ein großer Erfolg, der viele neue wissenschaftliche und technische Erkenntnisse für unsere Arktis- und Tiefseeforschung gebracht hat. Alle Fahrtteilnehmer bedanken sich beim Kapitän und der Mannschaft von *Polarstern* für die freundliche Zusammenarbeit und die exzellente Unterstützung auf der technologisch anspruchsvollen Expedition.

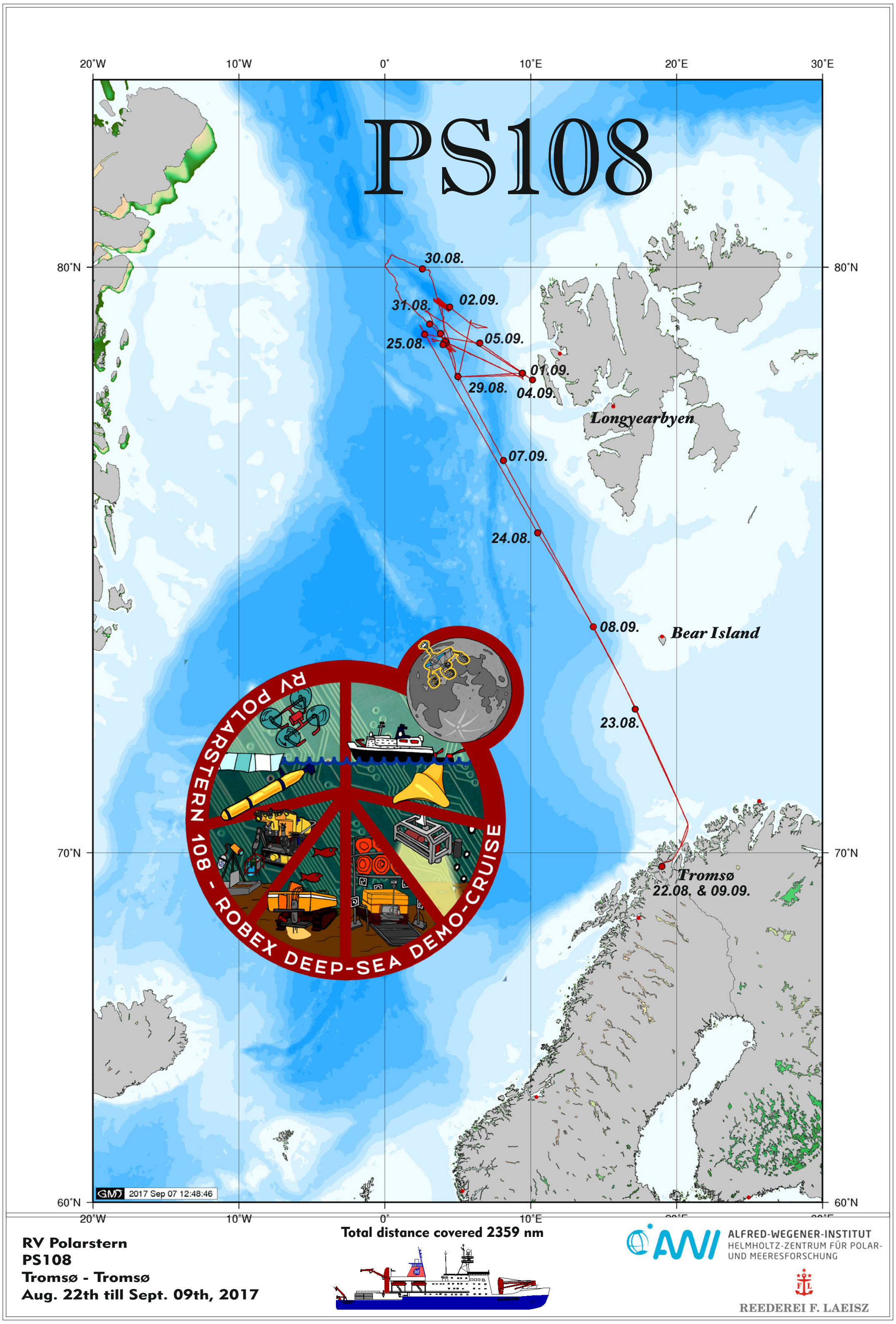

Abb. 1.1: Kursplot der Polarstern Expedition PS108 (22.08.-09.09.2017).
Siehe https://doi.pangaea.de/10.1594/PANGAEA.881582 für eine Darstellung des master tracks in Verbindung mit der Stationsliste für PS108.

Fig. 1.1: Course plot for Polarstern expedition PS108 (22.06.-09.09.2017).
See https://doi.pangaea.de/10.1594/PANGAEA.881582 to display the master track in conjunction with the list of stations for PS108.

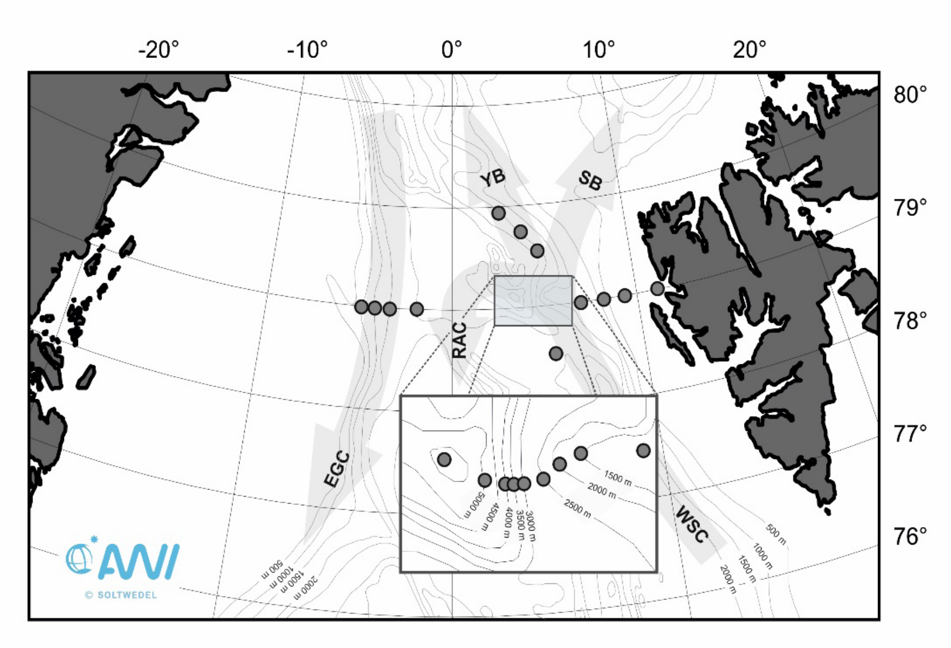

Abb. 1.2: Arbeitsgebiet LTER Observatorium HAUSGARTEN
Fig. 1.2: Working area LTER observatory HAUSGARTEN

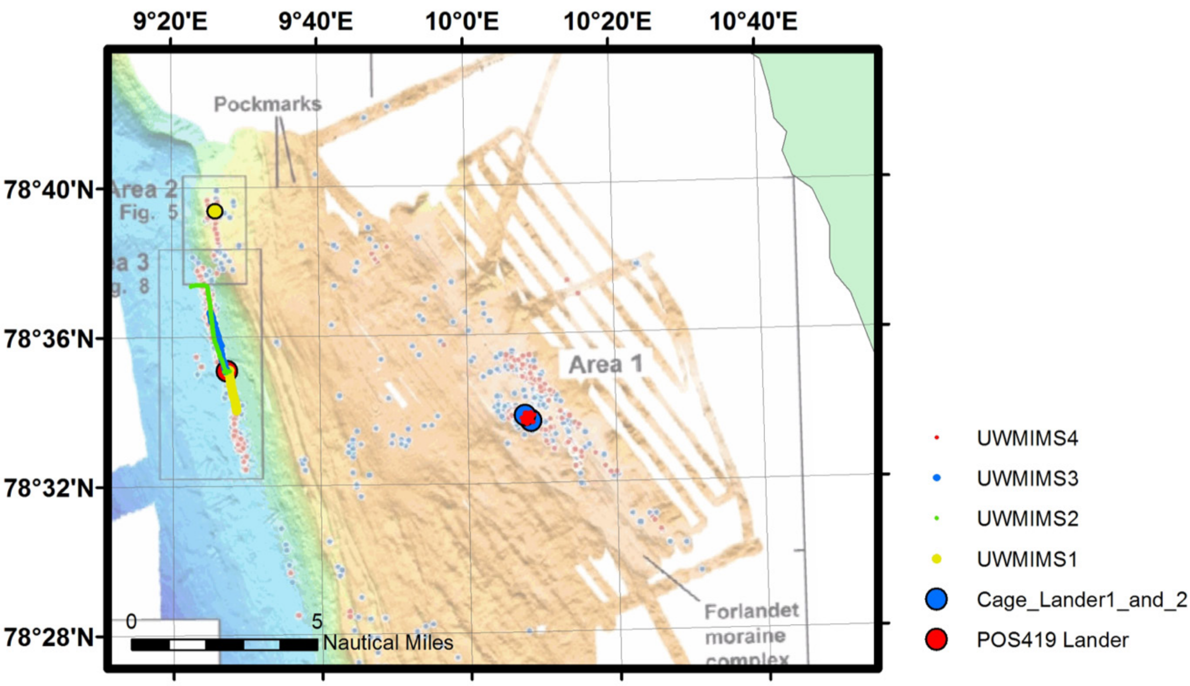

Abb. 1.3: Arbeitsgebiet Gashydrat Stabilitätszone vor Spitzbergen
Fig. 1.3: Working area gas hydrate stability zone (GHSZ) off Spitsbergen

SUMMARY AND ITINERARY

Research expedition ROBEX-DM (PS108) of RV *Polarstern* was dedicated to two major tasks: (I) testing the capability of new and innovative technologies, developed during the HGF Alliance ROBEX (Robotic Exploration of Extreme Environments), for exploration of extreme environments and deep-sea observations and (II) performing measurements and sampling at the HAUSGARTEN experimental sites using the ROV KIEL 6000. *Polarstern* operated mainly in two working areas (Fig. 1.1), in the eastern Fram Strait at the deep-sea observatory HAUSGARTEN (Fig. 1.2) and the gas hydrate stability zone (GHSZ) off Spitsbergen (Fig. 1.3). Our ability to address questions concerning ocean change is fundamentally limited by the lack of key technologies enabling *in-situ* experimentation, conducting targeted sampling, and performing persistent sensor measurements. During the expedition newly developed technologies, including 3 different types of benthic crawler, each designed for its specific scientific purpose, a glider, unmanned aerial vehicles (UAVs) to support AUV operations at the ice edge, and sensor systems like long-term oxygen profiler and underwater mass-spectrometer were used to study biogeochemical processes in the ocean. This on the one hand demonstrated the interoperability and verification of mission critical robotic technology required to operate in extreme environments and to perform continuous ocean observations. In addition, the expedition contributed to investigations in Arctic ecosystems strongly influenced by climate change, such as marine arctic sediments hosting gas hydrates and arctic deep-sea benthic communities. At the gas hydrate stability zone (GHSZ) off Spitsbergen water column gas concentrations at different spatial and temporal scales were monitored and quantified. At the HAUSGARTEN deep-sea observatory in the eastern Fram Strait, studies on the pelagic-benthic coupling were performed, to investigate how benthic life is governed by the food supply from surface waters contributing the research program PACES-II (Polar regions And Coasts in the changing Earth System) of the Alfred Wegener Institute Helmholtz Center for Polar and Marine Research (AWI). The expedition was also used to accomplish installations for the HGF infrastructure FRAM (FRontiers in Arctic marine Monitoring). The “Remotely Operated Vehicle, ROV KIEL 6000 (GEOMAR) supported our scientific investigations as well as the verification of the robotic developments.

On Tuesday August 22 at 19:00 *Polarstern* left Tromsø with an unusual freight on board into direction of Svalbard. Unusual, because 10 of the 40 scientists on board are space experts and special are also the new and innovative robotic systems, which should improve our capabilities in deep-sea research. The new robotic technologies have been developed since 2012 within the Helmholtz-Alliance ROBEX where 120 scientists and engineers from 16 space and deep-sea institutions all over Germany worked together.

We reached our working area on August 24 and started the research programme with the deployment of two bottom lander systems capable to measure oxygen consumption rates at the seafloor. These measurements are part of the long-term investigations performed at the LTER (Long-Term Ecological Research) observatory HAUSGARTEN. During the night a CATAMARAN, a system that is dragged over the surface of the sea, was used in order to collect litter and micro plastic.

In the morning of August 25 the ROV KIEL 6000 (GEOMAR) was deployed, directly at the start position of the crawler TRAMPER deployment one year ago (during PS99.2). During its one-year operation TRAMPER performed measurements of the oxygen distribution in the seafloor. Because of the weather recovery of the crawler was not possible at this time.

With the towed video and photo system OFOS a survey transect to the deepest point of the Arctic Ocean, the Molly Deep (5.500 m depth), was performed. The last operation in this area was 20 years ago. On the photos a bustle of life was recognized with countless small sea cucumbers and sea anemones. Furthermore, a lot of wood and unfortunately much more litter could be seen. The new dataset will be compared with the data from 1997 and might provide hints about the change of this ecosystem.

The second ROV dive focused on a biological long-term experiment, which was started last year. A common feature in polar deep-sea regions is the occurrence of so-called “dropstones” at the seafloor, which enhance the topographic heterogeneity and alter related hydrodynamic patterns. There is abundant evidence that habitat structures have important effects on spatial distribution patterns of benthic fauna populations in deep-sea environments. Until now we have not known how fast benthic communities reacts on new dropstones. During the ROV-dive sediment cores were retrieved from surface sediments influenced by the dropstone and nearby undisturbed areas as controls. The cores will be sub-sampled for meiofauna/nematode analyses and different biochemical parameters indicating food availability.

During the night of August 26 until the afternoon of August 27 the intermixed water of the Arctic and Atlantic Ocean was in the focus of interest. In terms of biological activity, the polar marginal ice zones (MIZ) are among the most relevant regions in the world. Previous observations suggest the high biological activity to be triggered by physical and chemical processes, which take place in the upper water column in the MIZ. With ship-based sensors for temperature, salinity, chlorophyll a, pressure and flow velocity the zone were both water bodies start to mix was identified. Afterwards the AUV PAUL, equipped with various sensors was used to investigate this mixed layer in more detail.

In the afternoon of August 27, we were able to get TRAMPER back on board after its one-year mission at the seafloor. The first investigations showed that Tramper did an almost perfect job until the deadlock of the right caterpillar. The crawler performed 24 measurements during the first half-year of its mission which will improve our knowledge about the seasonal variations of the oxygen distribution in the seafloor.

During several nights and early morning hours an under-water-membrane-inlet-mass-spectrometer (UW-MIMS) has been deployed to detect dissolved gases in the gas hydrate stability zone (GHSZ) off Spitsbergen. In this region along a 25 km long stretch methane is released from the seafloor into the water column at the upper boundary of the GHSZ at about 400 m water depth. In echo-soundings gas release can be easily detected and hence was used for the detection and mapping of gas release. The UW-MIMS has been deployed for the first time during this expedition under harsh *in-situ* and ship operation conditions. Overcoming first difficulties to run the system at the beginning of the cruise, during the third deployment we were able to successfully measure methane simultaneously to other dissolved gases.

A new type of underwater glider – MAPPA - was deployed from board *Polarstern* for the first time. After successful completion of some critical tests the glider, that is based on a blended wing design, performed a 1-hour dive down to 105 m water depth.

During our work at the ice edge at 80°N the AUV PAUL was able to dive for 3 hours without contact to the control room at *Polarstern* for track control, under the sea ice and back. This successful dive will provide new and valuable data for studies of the sea ice – ocean interface.

On the evening of August 31, there was an ROV dive to recover a long-term experiment on settlement in the deep sea. The experiment consisted of a weighted frame and 46 attached plates made from hard materials. The experiment was started in 1999 to show how communities develop over time on hard substrata. The recovery ends the time-series and brings new information on deep-sea growth to the surface. Altogether, there were 4 species of Foraminifera (single-celled organisms) and about 10 species of animals. Samples from the settlement frame allow for an analysis of growth rates of these deep-sea animals and also development of animal communities in the Arctic.

The towed camera system OFOS (Ocean Floor Observation System) was used during the nights to conduct five transects at the Molloy Deep, Kongsfjord Canyon, Hayes Deep, and at the northernmost HAUSGARTEN station (N5). Analysis of the OFOS imagery will enable us to assess if megafaunal densities and diversity on the seafloor of depressions and canyons differ from open slope areas.

A second test mission of the new robotic system MANSIO-VIATOR was started in the evening of September 4. The system consists out of a deep-sea crawler VIATOR and a non-mobile lander MANSIO. This was the first time the system was deployed at a water depth of 1,276 m at Vestnessa Ridge, western Svalbard. After a thorough survey with the ROV KIEL 6000 we could position the device accurately at the seafloor. After waiting for the programmed sleep mode to end VIATOR started to move autonomously. While leaving the hangar unfortunately several issues with the drive train were encountered that could be partially fixed by aborting the mission via an acoustic link (USBL). At the end of this VIATOR deployment a successful docking of the crawler into the lander was performed.

After the recovery of Tramper, the system was renewed and deployed again on September 3 for its second 12-months' mission on the Arctic seafloor. We will recovery TRAMPER next year during the expedition MSM77. A second crawler – NOMAD -, which will additionally study seasonal variations in biogeochemcial processes at the seafloor, was successfully tested. Besides measuring oxygen consumption rates, NOMAD is able to take images of the spatial distribution of the settling labile organic matter.

In the afternoon of September 6, our research activities came to an end and we started our return. The cruise ended on September 9 in Tromsø. The expedition was a great success. On behalf of all participants we would like to thank the captain and the crew of *Polarstern* for the friendly cooperation and excellent support with work at sea during this technological very challenging expedition.

2. WEATHER CONDITIONS DURING PS108

Jens Kieser, Hartmut Sonnabend DWD

The research cruise PS108 started in the evening of 22 August in Tromsø. An overcast sky and rain accompanied *Polarstern* through the fjords. During the night of 23 *Polarstern* reached the Norwegian Sea. The cruising area was situated on the edge of a high pressure zone causing calm weather during the first day at sea. An air temperature around 9°C was measured, while a light to moderate wind blew from southwesterly directions.

During the days between 24 and 26 August the anticyclonic center shifted from the Barents Sea towards Siberia. In the evening of 24 *Polarstern* arrived at the research and working area HAUSGARTEN. The region was influenced by a cyclone formed over the Fram Strait on the 24. In the working area a strong southwesterly to westerly air current established. It carried a moist air mass into the working area. Rain showers, drizzle, and light snow showers occurred. Outside of precipitation visibility remained good. The temperature dropped from about 8°C to values around the freezing point. Significant wave heights between 2 and 3 m were observed.

By 27 August over the western Fram Strait a further depression had formed, while its predecessor drifted away to the north. The new depression merged with the trough of an intense Iceland low that expanded to the Fram Strait on the 28. The working area close west to Spitsbergen was crossed by the trough. The list of the relevant pressure systems was completed by a high pressure ridge extending from Scandinavia to the sea area east of Svalbard. Due to the pressure constellation described above a fresh (5 Bft) southwesterly wind blew over the working area on the 27. Under a clear sky temperature increased to values significantly above zero. During the 28 a cloudy sky dominated and rain showers appeared over the working area. Southerly winds blew fresh in the morning and calmed down later. An air temperature around 5°C was measured. The trough passed the working area during the night of 29 August. Wind shifted to northerly directions and increased continuously to 6-7 Bft in the evening of the 29. In northerly winds the temperature declined to values near the freezing point. In the morning of the 29 fog patches caused a poor visibility temporarily.

In the morning of 30 August a strong northerly wind blew over the working area. About minus 5°C appeared, the lowest air temperature measured on PS108. Also during the day temperature of ambient air and water did not climb above zero. *Polarstern* cruised northwestward from the central HAUSGARTEN into an area with partial sea ice cover. The northerly winds abated as a high pressure ridge approached from the west. In the evening of 30 *Polarstern* reached the northernmost point of the cruise PS108 near the junction of 80.1° north and the prime meridian. On 31 August the high pressure ridge crossed the cruising area eastward and wind shifted back to southerly directions. After a period of light air motion in the morning winds strengthened up to 5 Bft in the evening. At this time *Polarstern* returned to the central HAUSGARTEN. The air temperature increased gradually above the freezing point.

At the beginning of September the research area got under the influence of a low pressure zone extending from the Greenland Sea to the western Fram Strait. Strong southerly winds carried a temperate air mass into the research area west of Spitsbergen. Rain and drizzle occurred.

On 2 September the working area was influenced by a depression over the Fram Strait. Windy and unsettled weather dominated. Since gale force winds and significant wave heights around 3 m were expected over the area close west of Spitsbergen, the originally scheduled working area this day, we moved northwestward towards the low pressure center where more moderate weather conditions were predicted. Here southeasterly winds of 5 to 6 Bft appeared.

Also the following day was characterized by the influence of the low centered over the Fram Strait. Windy weather continued. In the afternoon of September 3, a secondary low passed the working area and wind calmed down for a while. Afterwards wind veered to westerly directions. Temperature revert below the freezing point. Rain, drizzle and light snow showers occurred. Fog patches drifted through the working area.

Many clouds and drizzle dominated the weather impressions on 4 September. Westerly winds eased, as the low over the Fram Strait drifted northeastward followed by an intermittent high. A cold air mass was carried to the working area close west of Spitsbergen. Due to the relatively warm water in that area the temperature increased to about 3°C.

On 5 September the high pressure zone was located already north of the working area. From a low near Iceland a trough was building across the Greenland Sea to the Fram Strait. After a calm night an easterly or southeasterly wind increased up to 6 Bft. *Polarstern* moved from the eastern HAUSGARTEN to the northwestern edge of the HAUSGARTEN where partial ice cover and water temperatures below 0°C were observed. In a moist air mass carried into the working area, temperature of air dropped from 6°C to 2°C and fog appeared. The situation regarding temperatures, winds and visibility did not change until the afternoon of 6 September. Only when *Polarstern* left the HAUSGARTEN towards Tromsø in the evening of the 6th temperature of water and air increased and fog was replaced by higher clouds. Now a remarkable pressure gradient developed over the Fram Strait between a high over Franz Josef Land and a low over the sea area of Jan Mayen. The southeasterly wind increased further on. It reached 8 to 9 Bft in the morning of the 7th. In response of gale force winds the significant wave height reached about 5 m. Later in the afternoon winds and sea state abated as well as the visibility. We cruised through a foggy sea area where temperatures of air and water rose continuously to about 9°C in the evening of the 7th.

The extensive high near Franz Josef Land and a low moving from the sea area north of Scotland to the North Sea influenced the weather over the northern Norwegian Sea during the last period of the research cruise PS108. Between both pressure systems southeasterly winds of 4 to 5 Bft blew over the cruising area, increasing slightly in the evening of 8 September. The significant wave height increased slightly from about 2 m to 3 m. Mist and fog patches caused a poor visibility until noon temporarily.

In the morning of 9 September *Polarstern* arrived Tromsø with light to moderate winds from variable directions.

3. ROBEX - ROBOTIC EXPLORATION OF EXTREME ENVIRONMENTS

Martina Wilde AWI

Grant-No. AWI_PS108_00

The Helmholtz Alliance „Robotic Exploration of Extreme Environments – ROBEX" brings together the world's first integrated space and deep-sea research group under the coordination of AWI. A total number of 120 scientists of 16 institutions from all over Germany are jointly developing technologies to improve the exploration of environments with extreme conditions such as deep sea, polar regions, the Earth's moon and other celestial bodies.

During the last year of the Helmholtz Alliance ROBEX – 2017 - the jointly developed technologies have been demonstrated for the moon and deep sea scenario in the so-called demo-missions.

The ROBEX Deep-Sea Demonstration Mission has focused on Arctic ecosystems that are strongly influenced by climate change, marine Arctic sediments, which contain gas hydrates and Arctic benthic habitats in the deep sea.

In July 2017 the ROBEX Moon-Analogue Mission took place on Mount Etna: Therefore, the ROBEX lunar scientists have chosen the installation of an active seismic network on the Moon's surface as scenario. Main focus here is the measurement of the internal structure of the Moon and the composition of the lunar regolith. Other scientific questions are the existence and composition of a central core and if there is any seismic activity.

The ROBEX Moon-Analogue Mission consisted of two different experiments: First, the rover took the seismometer box from the lander autonomously and then traversed from the lander site to the first measurement point. The rover deployed the seismic instrument, waited until one measurement cycle is done, took it up again on the rover and repeated the measurement. In a second scenario, located close to the lander site, the rover had to set up a seismic network consisting of four instruments that had to be arranged at three corner points of an equilateral triangle of 100 m and one such seismometer in the center of this area.

In principle we saw that the deep sea community did benefit from the technologies and software developments that are already being used successfully in spaceflight. For example: the software and navigation markers used for docking the Automated Transfer Vehicle (ATV) to the International Space Station (ISS) are now being deployed in deep-sea research and are enabling an unprecedented level of autonomy. On the other hand the space experts have acquired technological approaches such as modularity. They also gained the courage to work in extreme environments and adopt the pragmatic approach that is helpful for such experiments on a real volcano.

3.1 Crawler system TRAMPER

Frank Wenzhöfer[1,2], Michael Hofbauer[1], Corinna Kanzog[1], Johannes Lemburg[1], Axel Nordhausen[2]

[1]AWI
[2]MPI

Grant-No. AWI_PS108_00

Objectives

Polar regions play a central role for the global climate. Rapidly changing physical and chemical conditions, as observed and projected for the future, will affect the ecosystem functioning including productivity, remineralisation, and energy flow between ecosystem compartments. At the HAUSGARTEN deep-sea observatory (FRAM Strait at about 79° N), studies on the pelagic-benthic coupling have been performed since 1999 to investigate how benthic life is governed by the food supply from surface waters.

Oxygen is a key molecule in earth ecology and global element cycles. Produced by photosynthesis, oxygen is the ultimate electron acceptor for organic matter mineralization and thus directly connected to the carbon cycle. A lot of our knowledge on oxygen exchange and carbon mineralization at the ocean floor originates from high-resolution studies of oxygen distributions and fluxes at the sediment-water interface. These studies allow determining the amount of organic material that escapes mineralization and is retained in the sediment record.

In-situ measurements in the Arctic are usually limited to the ice-free summer periods, thus limiting our knowledge on the dynamic range of seafloor remineralization processes. The fully autonomous benthic crawler TRAMPER is capable to record sediment oxygen distributions over a full annual cycle with translocation between consecutive measurements (Wenzhöfer et al., 2016). The new generation of optode-based oxygen monitoring system mounted on a fully autonomous crawler will help to establish high-temporal resolution benthic flux measurements in order to determine seasonal variations in organic matter turnover and benthic community respiration activity, and to close the carbon budget for the deep Arctic Ocean.

Work at sea

TRAMPER, deployed during *Polarstern* expedition PS99.2 in summer 2016 at HAUSGARTEN station HGIV at 2,500 m was recovered (Fig. 3.1.1). During its mission the crawler, equipped with a multi-optode-profiler, was pre-programmed to perform >52 sets of vertical concentration profiles across the sediment-water interface (one set each week) along a ~1 km transect. Before recovery, the ROV KIEL 6000 (GEOMAR) was deployed, directly at the start position of the crawler TRAMPER deployment one year ago to search for the crawler to get a first impression on its condition after one year. The search for the starting point was quite short and then the observers were able to recognize the tracks of TRAMPER in the sediment. The ROV followed them and after 20 minutes TRAMPER was recognized standing there vertically to its tracks (Fig. 3.1.2). The reason was that after around 350 m and 24 weeks of travelling at the seafloor the right caterpillar did not work anymore and TRAMPER stayed the rest of the year in a mode of circling. However, the crawler operated without maintenance for more than 1 year collecting scientific data.

After recovery, Tramper was renewed (exchange of sensors and batteries, and repair of the broken motor) and deployed again for its second 12-months mission at the Arctic seafloor. We will recovery Tramper next year. A second crawler – NOMAD (Fig. 3.1.3) -, which will additionally study seasonal variations in biogeochemcial processes at the seafloor, was successfully tested at HG-II. Besides measuring oxygen consumption rates, NOMAD is able to take images of the spatial distribution of the settling labile organic matter. The deployment showed that all systems work but due to the very short bottom time no scientific data could be collected.

Fig. 3.1.1: Tramper recovery after 1-year mission

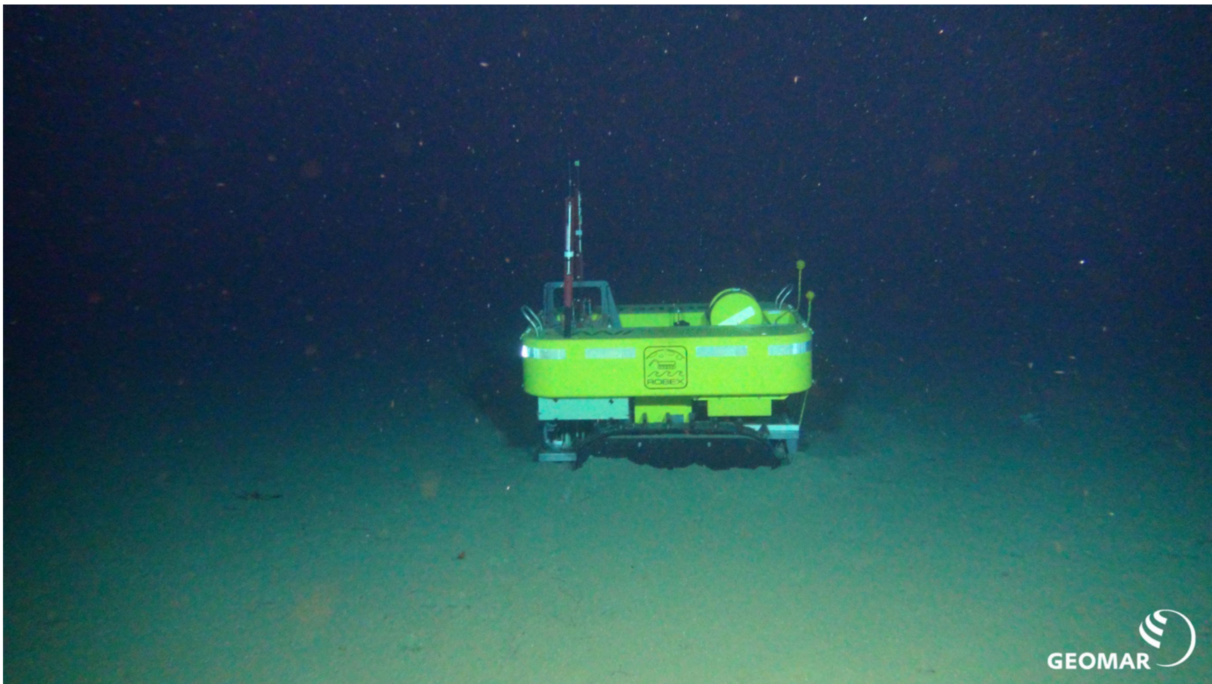

Fig. 3.1.2: Following the Tramper tracks at the seafloor (Photo: ROV KIEL 6000, GEOMAR)

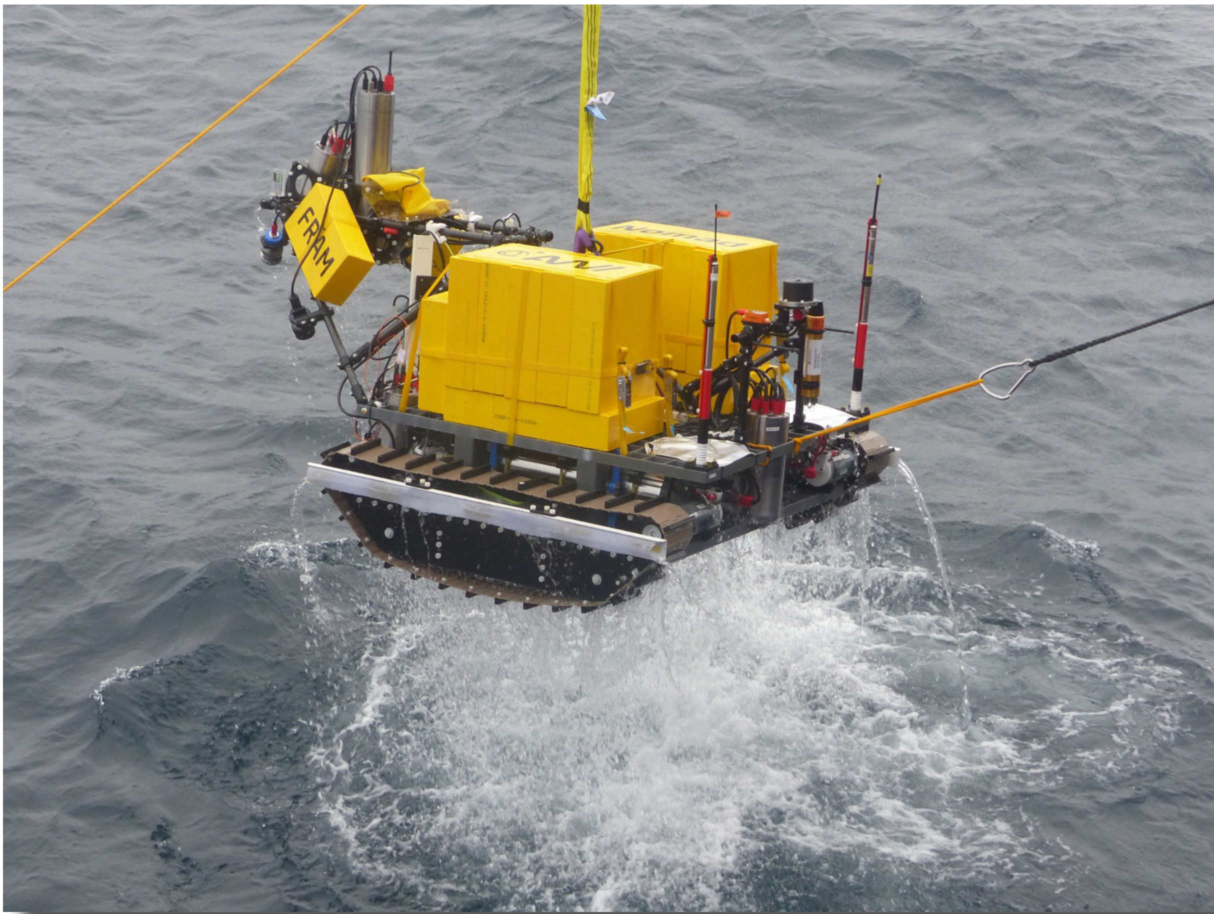

Fig. 3.1.3: Recovery of Nomad after its first in-situ test

Preliminary results

When recovered, Tramper had moved a distance of 360 m and performed 59 measurement cycles. This allows now to investigate the deep seafloor in remote areas and over longer time periods, which was previously not possible.

The first investigations showed that TRAMPER performed 24 measurements during the first half-year of its mission which will improve our knowledge about the seasonal variations of the oxygen distribution in the seafloor. The retrieved oxygen profiles will be used to calculate benthic oxygen consumption rates which can then be converted to carbon equivalents. This allows determining the seasonal variations in organic matter mineralization.

Data management

Not applicable.

References

Wenzhöfer F, Lemburg J, Hofbauer M, Lehmenhecker S, Färber P (2016) TRAMPER - An autonomous crawler for long-term benthic oxygen flux studies in remote deep sea ecosystems. OCEANS 2016 MTS/IEEE Monterey, 1-6. doi: 10.1109/OCEANS.2016.7761217.

3.2 Crawler system MANSIO-VIATOR

Sascha Flögel[1], Thorben Berghäuser[1], Dimitar Saturov[1], Olaf Pfannkuche[2], Detlef Wilde[3], Ingo Ahrns[3], Christof Nuber[3], Marc Hildebrandt[4], Johannes Lemburg[5], Jakob Schwendner[6]

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[5]AWI
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Grant-No. AWI_PS108_00

Objectives

The expanding need for tools to investigate larger parts of the world oceans such as the shelf seas and continental margins for scientific reasons is continually increasing. Simultaneously, our ability to address questions concerning ocean change is fundamentally limited by the lack of robotic key technologies for enabling *in-situ* experimentation and observation performing persistent sensor measurements in the ocean. The work carried out during the ROBEX deep-sea demo cruise will test the capability of the innovative GEOMAR MANSIO-VIATOR robotic system.

At the GEOMAR Helmholtz Centre for Ocean Research Kiel, the MANSIO-VIATOR (latin: harborage-traveller, Fig. 3.2.1) system was designed. It comprises a stationary lander system and a mobile deep-sea crawler. The hangar is used for transport to the site of investigation and for recovery at the ocean surface as well as to recharge the lithium polymer accumulators on the crawler. The hangar facilitates data transfer from the lander system to the crawler and ultimately to the sea surface by acoustic modem. Within ROBEX, this approach is closest to the lander-rover systems used in space research and thus a true space analogue. After a video-guided deployment the system has been designed to operate fully autonomous for scientific missions of up to 6 months. 2013 and 2014 saw the design and construction of both, the crawler VIATOR and the lander/hangar system MANSIO. This involved careful evaluation of existing energy resources (rechargeable LiPo cells) as well as development and testing of an inductive energy transfer system. Furthermore, we decided upon hard- and software needs for the far-field (camera system, laser scan together with DFKI) and near-field navigation (optical, reflecting binary markers; AIRBUS) which included the design and construction of pressure housings. Furthermore, we have currently implemented a new USBL system to improve navigational needs on longer distances. This cruise meant to finally test the new system incl. USBL, wheel and visual odometry (Kraken Robotic) and updated marker-based docking procedures.

Work at sea

During the cruise we had the chance to test the system twice at to different localities. First, we deployed MANSIO-VIATOR on August 28 at a water depth of 247 m in the Gas Hydrate Stability Zone (GHSZ) west off Prins Carl Foreland (Svalbard) at 78°39,38´ N and 9°25,91´E (station PS108_16; Fig. 3.2.2). First, the ROV KIEL 6000 was deployed and lowered to the bottom to perform a survey of the deployment site. Once a suitable location was found the system was lowered to the sea-floor. The complete operation was video- and photo documented by the ROV. Unfortunately, we encountered problems in the pre-programmed timeline and the crawler did not leave the hangar. This led to an abortion of the mission and the retrieval of the ROV and MANSIO-VIATOR on deck. After fixing software and minor hardware issues we prepared the system for it’s second test mission. This time, on September 4 at a water depth of 1,276 m at Vestnessa Ridge (79°02.851´ N and 6°32,175´ E, west of Svalbard).

Fig. 3.2.1: MANSIO-VIATOR during deployment on Polarstern (© Lemburg)

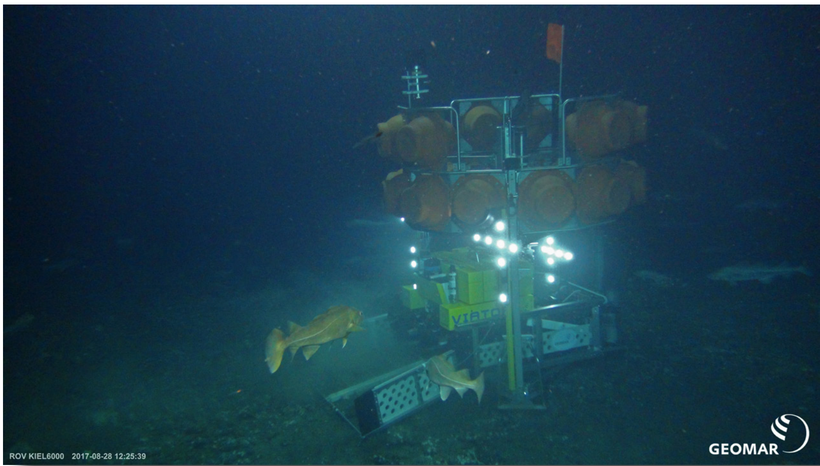


Fig. 3.2.2: MANSIO-VIATOR on the sea-floor in 245 m water depth at station PS108_16

The system (station PS108_47, Fig. 3.2.2) left the deck at 20:15 and was lowered to the sea-floor where the ROV was already waiting to document the operation. The system was detached from the launcher at 21:33. After waiting for the pre-programmed sleep mode of two hours to end the crawler started the first timeline, switch on lights, start logging and move 3 m back. Unfortunately, we encountered problems with the drivetrain that slowed the left chain. As a result the crawler turned left. Thus, we decided to interact with the ROV and repositioned the crawler who completed its timeline. After a USBL induced mission abort and ROV repositioning, software issues could be fixed. Ultimately, this led to the first successful deep-sea docking of MANSIO-VIATOR.

Technical components and first results

Marker based navigation

1. The Autonomous Docking Function of VIATOR

The VIATOR crawler is equipped with an autonomous docking function that allows automatic homing of arbitrary positions and orientations pointing towards the MANSIO. This function is foreseen to bring the VIATOR into a defined position and orientation directly in front of the MANSIO ramp. From this position – the docking point – the VIATOR is usually able to return into the MANSIO by simple forward movement commands that stop after a mechanical end switch is pushed.

For the navigation between the VIATOR and the MANSIO, an active light pattern is used that can be recognized by VIATOR. The known positions of the light markers allow the accurate computation of the relative transform between the docking point and VIATOR's current position.

2. The Docking Process

Once the VIATOR shall return to the MANSIO, the autonomous docking function is started by the mission manager (Fig. 3.2.3). Since it is not precisely known at the beginning of the docking process where the MANSIO is located the first step consists of a search mode. In this mode, the pan-tilt-unit starts turning from left to right and vice versa in order to get a first view of the MANSIO and the light-markers. During this search-process the marker-detection and tracking module is running trying to recognize the markers and to compute the relative position and orientation between VIATOR and MANSIO. After several recognitions, the docking process analyses the quality of the computed transformations and if the quality is sufficiently good the guidance-module of the docking-function generates a cubic spline as a trajectory towards the MANSIO. This trajectory is then transferred to the control-function that commands the left and right drivetrain of VIATOR to move along the planned trajectory. During this process, the controller needs permanent updates of the current positions and orientations w.r.t. the light-markers of MANSIO. Since it is possible that VIATOR moves along curves, the pan-tilt-mounted camera has to keep the markers in the camera's field of view. For this purpose, the marker tracking is also used to command the pan-tilt-unit to track the MANSIO during VIATOR's approach movements. The following figure shows all components of VIATOR involved in the docking process.

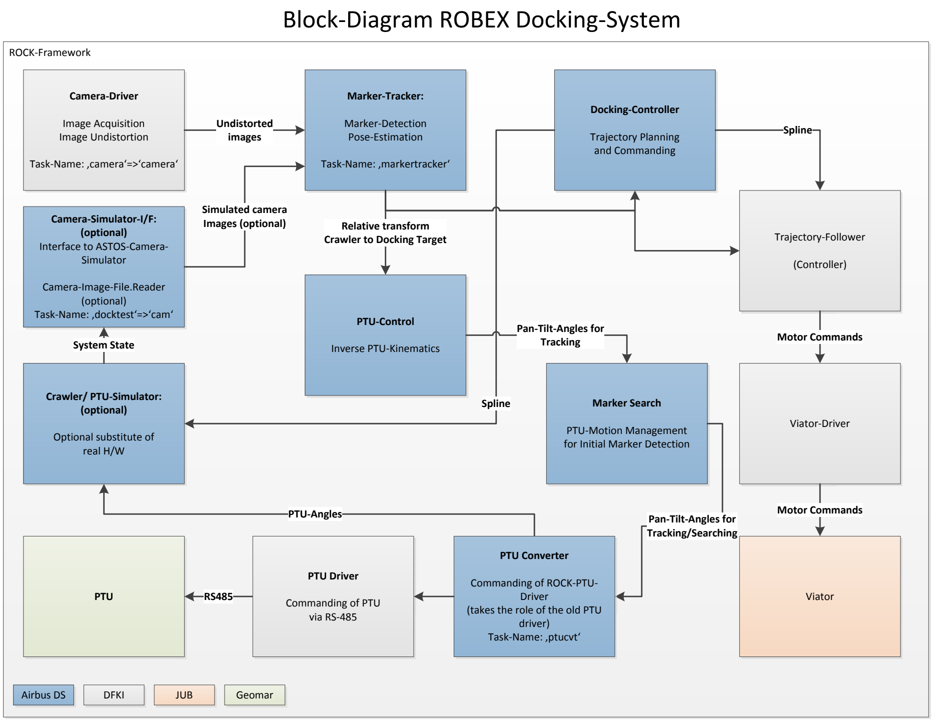


Fig. 3.2.3: Block-diagram of VIATOR's docking function

3. Marker-Based Navigation

The MANSIO is equipped with three marker-crosses each consisting of 7 LED lights (Fig. 3.2.4). The markers are quite bright to assure maximum visibility even in poor visibility conditions due to marine snow or turbidity. The marker-recognition is able to recognize each marker cross even in the presence of other bright objects. For this purpose, the marker recognition applies the well-known cross-ratio of the distances between 4 collinear points. The cross ratio is invariant under perspective projection and therefore very useful for the identification of groups of four collinear points. The intersection of two such groups forms a marker-cross and provides the basis for the relative pose-estimation. The pose-estimation is running a perspective-n-point algorithm.

An essential function of the navigation module is the automatic exposure-time control. That controls the exposure time of the camera such that the markers of the MANSIO are perfectly depicted without seeing too much disturbing background features in the image. Furthermore, this function allows the detection of the lights even in difficult visibility conditions caused e.g. by suspension-clouds.

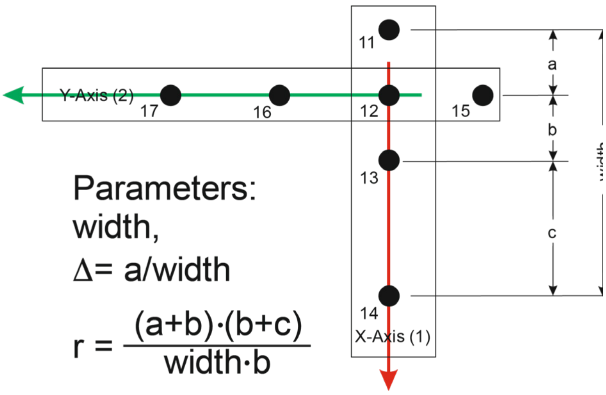


Fig. 3.2.4: Coordinate system of a cross-ratio marker-group and definition of marker-group by its cross-ratio parameters width, delta and r (cross-ratio)

4. Experiments on PS108 Expedition

After several previous tests in laboratory, tanks and on *Alkor* research vessel, the final demonstration of this functionality has been shown during the PS108 expedition of the *Polarstern* research vessel to the Fram Strait near Svalbard.

At a depth of more than 1,270 m the VIATOR has left the MANSIO and performed several movements before it successfully docked to the MANSIO with the above mentioned docking-function. The following figures show some snapshots from these experiments, marker detection (Fig. 3.2.5) and operation inspection via sonar imaging (Fig. 3.2.6).

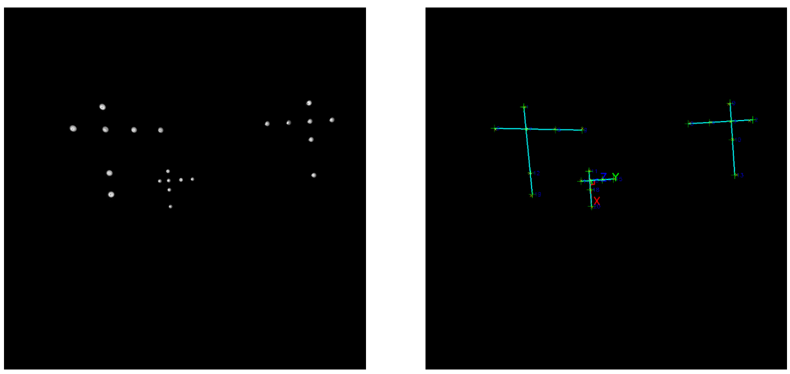
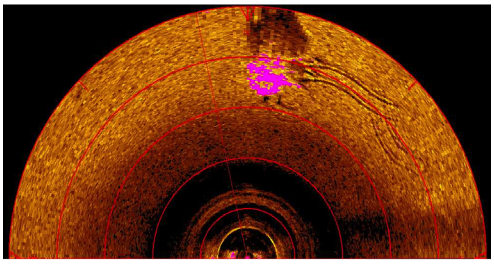


Fig. 3.2.5: Left: Camera image taken from the three marker crosses in front of the MANSIO. The exposure control assures a robust view of the LEDs without any disturbing background in the image. Right: Visualization of the marker-cross recognition.



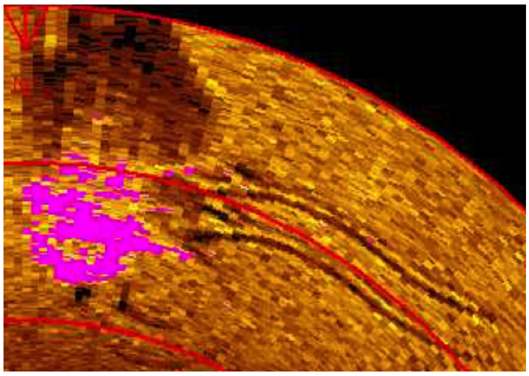


Fig. 3.2.6: Left: Sonar image taken from a remote-operated vehicle that observed the full process. Right: Zoom into sonar image showing the track of the VIATOR after it performed one docking manoeuvre.

System Command and Control Framework

The VIATOR robot consists of a number of sensors, actors and auxiliary systems, which all need to act in a tightly coupled fashion. This co-ordination is being handled by the ROCK middle-ware, developed at DFKI-RIC in Bremen. Each component of the robot is encapsulated as ROCK-component, which provides a unified communication layer between components. A supervision layer (called Syskit) provides the means to model the functionality of the robot using the ROCK-components as building-blocks. The Syskit layer also provides an interface to the mission-manager developed by AIRBUS. Once the system is modeled and all individual components have been implemented, the Syskit system can start and supervise the robot. It also handles logging of all exchanged data which is crucial for post-mission analysis, especially in a fully-autonomous system as used here.

During the sea-trials on PS108 the syskit system performed as expected, documenting the two missions undertaken. A total of 150Gb of data were recorded in the second, 11h deployment of the MANSIO-VIATOR system, consisting of camera images, robot odometry and scientific sensor readings to name a few. The only limitation recognized was the ability to log the camera data with more than 5 FPS due to the resulting load on the system. The reason for this was two-fold: due to a mistake during the modeling phase each recorded image was also pre-processed (camera calibration rectification and de-bayering), which should only have happened to the images being further processed by one of the on-line algorithms (e.g. docking). Secondly the processing power of the robot's PC system was not sufficient for logging of 15 FPS of 4MP images.

Robot Positioning and Localization

There are three systems which handle localization and positioning during missions with the VIATOR robot: dead-reckoning using odometry and AHRS data, USBL positioning between MANSIO and VIATOR and a visual-marker based docking procedure using the camera and pan-tilt-unit on the robot. The dead-reckoning component fuses the information of track-revolutions with the orientation data from the AHRS to produce a position estimate of the robot relative to its starting position in the MANSIO lander. This system relies on the assumption, that there is minimal track-ground slippage, which would decrease its accuracy. While the AHRS used (Xsens MTi-G) has magnetometers in addition to gyroscopic sensors for angular velocities, they could not be used for orientation stabilization due to the presence of too many sources of magnetic disturbance on both the robot as well as the lander.

The USBL positioning uses two devices: a USBL head mounted onto the lander and an acoustic modem head mounted onto the robot (Evologics 17/7 USBL-System). The robot modem interrogates the lander USBL, which uses this interrogation message to calculate the spatial angles relative to the modem, and communicates them back to the modem. The modem can then use the round-trip-time to calculate its distance to the USBL, and combine this distance with the spatial angles, resulting in a Cartesian position relative to the USBL head on the lander. This procedure is called reverse-USBL positioning. While its update rate is a lot smaller than the dead-reckoning described above (in the order of 0.2Hz), it has the advantage of being globally stable in its accuracy, providing a long-term stabilization for the dead-reckoning system. The visual marker-based docking is described separately in the previous section.

During the sea-trials on PS108 the dead-reckoning and USBL-positioning were working as independent localization entities, no cross-correction between the two modalities was performed. This was due to the fact, that the USBL was deployed for this purpose for the first time, and not sufficient data was available to perform a long-term stabilization of dead-reckoning using the USBL. Nevertheless both systems performed individually as expected. Despite the malfuction of the left track the robot position could still be estimated correctly. The recorded data will be post-processed in order to estimate the suitability of the combination of both sensor modalities in the future.

Communication and In-Situ Control

While the MANSIO-VIATOR-System has been conceptualized as fully-autonomous system, the addition of the USBL/Modem system onto lander and robot provided the possibility for remote intervention using a third USBL head deployed on the surface. This enabled the tracking of both systems from the ship as well as limited intervention during a mission. For this purpose two communication modes were implemented: a direct communication from the ship to the lander or robot, as well as an indirect communication with the robot using the lander as relay. The second mode was necessary, since the robot has no direct acoustic line-of-sight to the ship while parked inside the lander. A simple ASCII-based protocol was implemented discerning the different messages. The following commands have been implemented:

* Ship-Lander: Change brightness of docking-lamps
* Ship-Lander: Activate/Deactivate Charging
* Ship-Lander: Activate/Deactivate Message-forwarding
* Ship-Viator: bash-shell
* Ship-Viator: syskit-shell

The commands for the syskit- and bash-shells would be forwarded by the lander to the viator if message-forwarding was activated on the lander. Having access to the robot over one of the two shells complete control of the system is possible. The two limiting factors are bandwidth and dropped messages. The bandwidth of the USBL data channel is severely limited, each message can only transport 55 8-bit characters. Due to the limited speed of sound in water a transmission to a depth of 1,500 m takes one second each direction. This makes transfer of data nearly impossible, only commands can be transferred. The second limitation is more severe in comparison: since the USBL requires direct line-of-sight for reliable operation, all objects between lander/viator and the ship result in dropped messages. This could be remedied in theory by addition of a more secure transport-protocol, which will be investigated in the future.

During the sea-trials on PS108 the intervention was extensively used. Since it became apparent quite early that due to a problem with the left track a normal operation would not be possible, the mission execution was stopped using the bash-shell. Then a number of syskit-commands were sent in order to investigate the track problem, which was hindered by numerous dropped messages. Since normal operation could not be restored, a reboot of the on-board PC was initiated, followed by a docking attempt, which was successful. As a conclusion the intervention using the USBL-communication channel prevented the manual recovery of the VIATOR robot, the MANSIO with docked VIATOR could be remotely recovered by commanding a release of its drop-weights.

Preliminary results

Not applicable.

Data management

Not applicable.

3.3 MAPPA - probing the upper 200 m of the water column with a newly developed underwater glider

Christoph Waldmann[1], Sebastian Meckel[1], Bernd Langpap[2], B. Soppa[2], Detlef Wilde[2], Michael Ruffer[3]

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[3]UWürzburg

Grant-No. AWI_PS108_00

Objectives

The main objective of the glider deployments was to demonstrate the development status of the system in particular in regard to its operational capabilities. Besides the fact that the design promises higher payload capacity it has also been expected to demonstrate being able to take high quality measurements of salinity, density and oxygen in the upper 200 m of the water column because platform movements are minimal as there is no propeller used and the sensors are integrated at a position that causes no interference with the boundary layer of the platform. The underwater glider has been developed as part of the Helmholtz Alliance „Robotic Exploration of Extreme Environments-ROBEX“ and is primarily meant to support biochemical investigations in future open ocean deployments. In comparison to legacy glider systems the payload capability is about 10 times higher and another specific characteristic is the small gliding angle that allows for a better horizontal coverage of the depth range of interest which is for instance highly relevant for video investigations of particle fluxes in the upper 200 m.

The underwater glider has been developed as part of a cooperation between MARUM, AIRBUS, DLR, and University of Wuerzburg within ROBEX (Waldmann et al., 2014). The deployment was the first field operation from board a vessel. Following similar deployment routines as with the AUV PAUL of AWI has lowered the risks of testing the vehicle under field conditions.

Work at sea

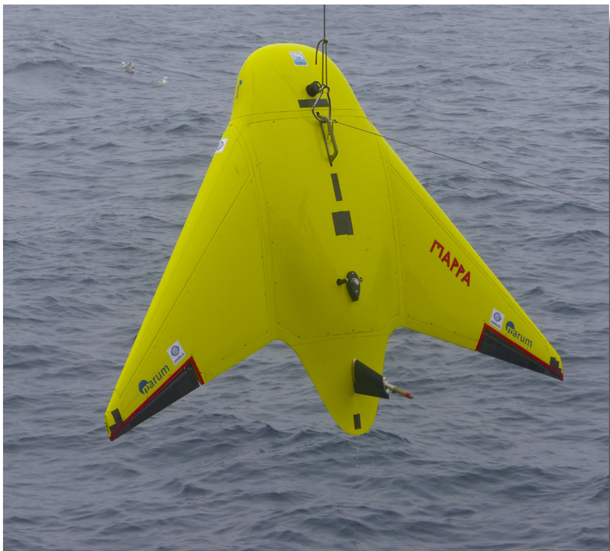

Fig. 3.3.1: Glider MAPPA during deployment on Polarstern

At the current development stage all deployment steps of the system have to be newly defined and closely monitored. This includes the development of specific pre-launch procedures that will ensure higher operational reliability. Furthermore, environmental conditions as for example avoiding drifting ice, which again is very similar to the AUV operation scenario, has to be taken into account. After the first tests the deployment and recovery procedures were revised and are now better adapted to the conditions of vessel deployments.

Station PS108_11-1 GLIDER MAPPA (27-08-2017, 79° 03,547’ N, 004° 10,297’ E)

A particular critical point of the glider operation is the weight adjustment of the vehicle in water. Although a preliminary weight balancing has been done at MARUM the final ballasting has to be done at sea. This operation is only successful if the waves are not too high as the orbital motion within the waves prevents a proper weighting. During the station PS108_11-1 the glider MAPPA (Fig. 3.3.1) was lowered into the water by crane and then left floating on the surface. After activating the buoyancy engine the glider was made to sink, float, and resurface. After that this cycle was repeated several times to make sure that both descent and ascent of the vehicle were safely carried out. It was found that no readjustment of the weight was necessary.

Station PS108_18-1 GLIDER MAPPA (29-08-2017, 78° 36,399' N, 5° 003,191' E)

The first flight mission has been prepared employing a pre-launch checklist that was developed by taking previous operational experience from lake tests into account. As part of the pre-launch check a simulation of a full dive cycle with activation of all actuator systems was carried out. While on deck making the system ready to deploy by crane an issue with the left rudder was detected. Therefore this rudder was set inactive, which although limits the controllability of the vehicle still allowed for a valuable test of the complete system. The glider was pulled on station by a zodiac of *Polarstern* and then released for its dive. After about 30 min the glider reached its maximum depth of 105 m. After reaching this target depth a trigger was set by the control system to start the buoyancy engine where the buoyancy of the system is raised by blowing compressed air into 4 bladders with a total volume of 10 l. This process initiated the ascent of the vehicle where the buoyancy force is about 5 kg. After 20 min the glider reached the surface and sent out its current position back to the ship. In case of any malfunction of the glider controller an emergency IRIDIUM transmitter will instead send out the position information.

In particular during that first deployment the operators were eager to follow the dive operation and vehicle trajectory of the system in real-time. This has been made possible by using the ship's GAPS USBL (Sonar Localisation) system where a matching transponder has been integrated into the nose of the glider. The horizontal distance travelled by the glider had been 700 m. Selecting a smaller glide angle or going to higher depths can extend this range.

Station PS108_49-1 GLIDER MAPPA (05-09-2017, 79° 02,983' N, 6° 28,660' E)

The preparation of the second flight mission followed strictly the scheme of the first mission starting with working through the pre-launch checklist. The left rudder had been repaired in the meantime so that now all actuators had been fully operational. The deployment followed the same steps as during the first deployment. However, the glider was pulled on position with a constant slow speed of the zodiac that overall accelerated the towing operation. At a depth of about 15 m the downward force equals the lifting force of the towing line so that the glider is traversed in a constant depth. When reaching the deployment site the glider resurfaced. After sending the dive command from the ship to the glider the system started its ascent to a maximum depth of 115 m. The descent command was again triggered by the controller system after detecting the target depth.

Tracking the underwater vehicle with the GAPS system has been more difficult in this case. It is assumed that this is related to the fact that the glider has been in the direct stern region of the vessel so that the ship's propeller might had a detrimental effect on the propagation of the acoustic waves. After turning the vessel by 45° a significant improvement of the GAPS signal had been achieved.

Both data sets the glider internally stored attitude data and the GAPS data are available for further analysis. Together with the ship's ADCP data a good picture of the flight trajectory and the overall flight behaviour can be derived.

Preliminary results

During the underwater flight of the glider a number of different attitude and vehicle status data were collected. To judge on the flight behaviour one starts inspecting the descent and ascent rates. Fig. 3.3.2 (second deployment) shows that the ascent rate is slightly higher then the descent rate which gives an indication that the glider is already well weight balanced.

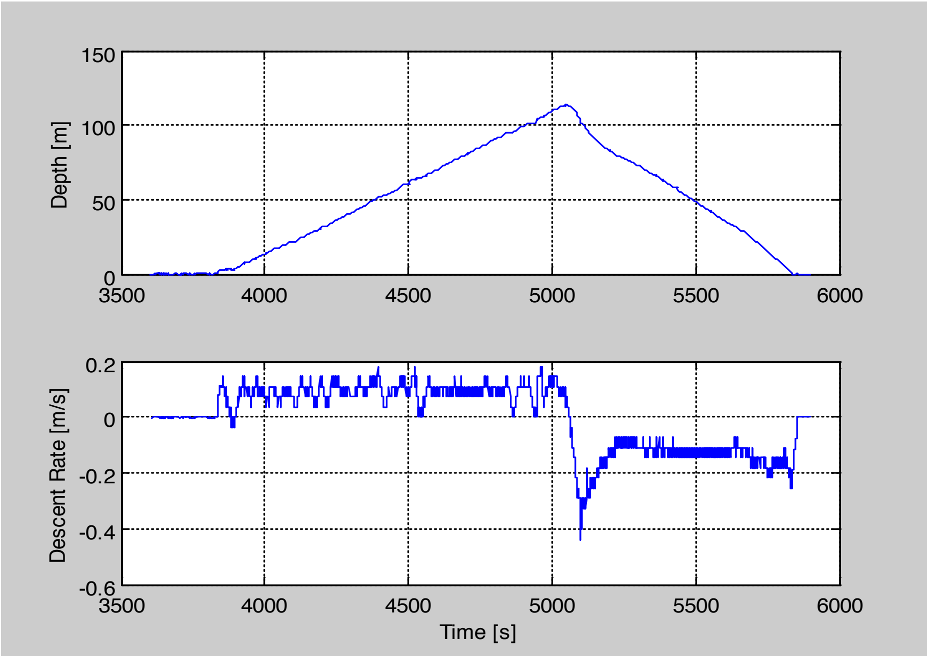

Fig. 3.3.2: Flight data of the second dive; Upper panel – Depth as a function of time (in seconds); Lower panel – Descent and ascent rate. The ascent command was initiated at t = 4,900 sec

The depth of the glider as a function of time gives indication of a smooth descent, which actually is misleading when the attitude data are evaluated.

In Fig. 3.3.3 those motion data (roll, pitch, heading) are displayed. As one can see the descent of the glider is connected with strong wiggling motions in all axes. The movements of the actuators, the rudders and the mass shift unit, also show evidence of an unstable flight behaviour. Obviously the control system tries to pull the nose down to the intended pitch angle, which was never reached. The reason for that behaviour is mostly likely related to the safety line that is connected upfront of the centre of gravity. The line is dragged behind the vehicle, which results in a lifting moment on the nose. It is assumed that this force counteracting the control system is dominating so that a stable flight attitude cannot be achieved.

As known from aircraft design the hull shape of the glider, a blended-wing design, is prone to yaw instability. Checking the heading data of the glider it appears that in the ascent phase of the dive the control system is able to suppress extensive yaw movements.

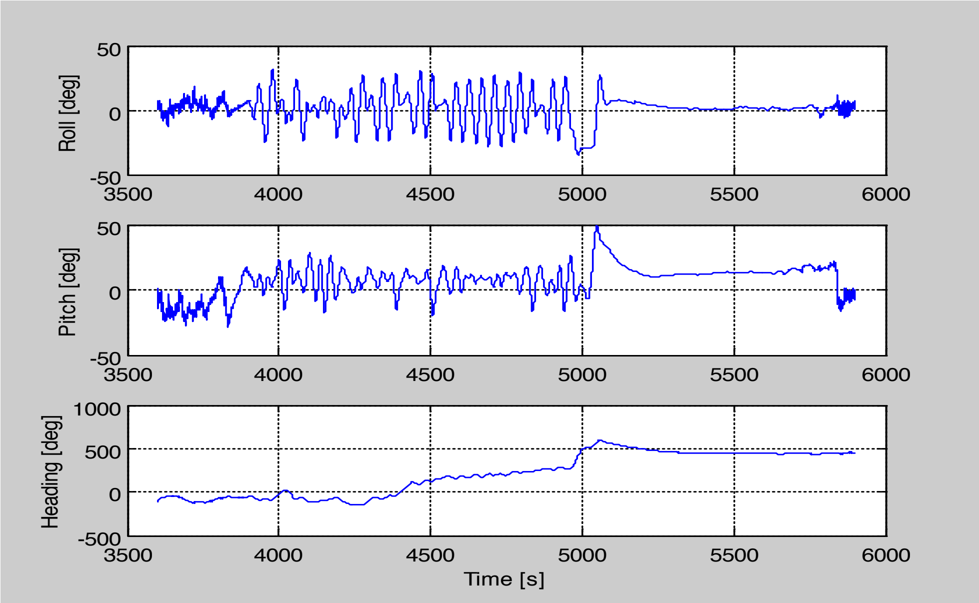

Fig. 3.3.3: The flight data (end dive) of the motion unit showing roll, pitch, and heading (yaw) as a function of time (in seconds)

The planned CTD measurements had not been carried out due to concerns in regard to changing the weight distribution of the glider.

Data management

No water column data were collected.

Acknowledgement

The members of the glider team acknowledge the excellent support and patience of the ship's crew during glider operation

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3.4 Gas measurements across methane seep sites off Spitsbergen using a novel underwater Membrane Inlet Mass Spectrometer (UW-MIMS)

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GEOMAR

Grant-No. AWI_PS108_00

Objectives

The Svalbard archipelago and its main western island Spitsbergen is located at a key juncture at the Arctic Ocean-Atlantic Ocean boundary. Particular importance of the area arises from the presence of subsea gas hydrates (Vogt et al., 1994; Vanneste et al. 2005) and active methane venting at the upper limit of the gas hydrate stabilization zone (GHSZ) (Westbrook et al., 2009). Methane flares were found along a 25 km-long stretch at the ~390 m isobath (Westbrook et al. 2009, Gentz et al. 2013, Berndt et al. 2014). Methane venting was also found to be vigorous. Recent work showed that the mode of the West Spitsbergen Current (WSC) flowing over the GHSZ zone influences the retention of methane in the water column (Steinle et al. 2015). These authors showed that with short-term variations in the WSC, new water masses can move in causing the replacement of the established methane- consuming microbial communities. Therefore, the source strength of methane seepage and its fate in the water column is strongly linked to hydrodynamic patterns over the Spitsbergen GHSZ seeps. The combined influence of hydrodynamics in association with distinct changes of water mass movements, changes in the source strength and microbial activity render the GHSZ extremely difficult to quantify the actual CH_4 emission. This area has been chosen as an ideal test site for a novel underwater mass spectrometer and allows comparison with previous CH_4 measurements in this region (e.g. Sommer et al. unpubl., Gentz et al. 2013)

Major aim of this cruise was to determine spatial variability of dissolved gases particularly CH_4 along transects across seeps in the GHSZ and a shallow seep site off Spitsbergen using a novel underwater Membrane Inlet Mass Spectrometer (UW-MIMS) combined with CH_4, pCO_2 sensors (Kongsberg). Technical aim was to demonstrate the successful underwater application of the UW-MIMS, which has been developed at GEOMAR within the Helmholtz Alliance ROBEX (ROBOTIC Exploration of Extreme Environments) under *in-situ* conditions.

Despite the potential for the wide application of *in-situ* mass spectrometers the use of this technology in aquatic sciences is still largely restricted (Chua et al. 2016 and references therein). Those few systems that exist are used predominantly for mapping of volatile hydrocarbons where a study addressing the Deepwater Horizon oil spill represents a prominent example (Camilli et al. 2010). Other recent examples of mapping volatiles focus on methane seep sites off Spitsbergen (Gentz et al. 2013), on the methane source strength of a blow out in the central North Sea UK (Sommer et al. 2015) or volcanic degassing of carbon dioxide around the Panarea island (Aeolian Islands, Italy, Schmidt et al. 2015). These studies (amongst others, see Chua et al. 2016) demonstrated that MIMS is a promising technology for the simultaneous detection as well as the quantification of volatiles. The latter two studies both conducted by GEOMAR were however *ex-situ* and relied on continuous in-line measurements on water that was pumped from the measurement site on board the ship.

Work at sea

The gas surveys focused on two working areas off Spitsbergen at the western side of the Prins

Karls Forland. Three deployments of the UW-MIMS were conducted at the GHSZ in water depths of about 400 m. Another deployment took place at shallow methane seep sites in water depths of about 90 m (Fig. 3.4.1; Table 3.4.1). The deployments UW-MIMS-1 and UW-MIMS-2 were used for *in-situ* tests to establish stable pressure conditions at the membrane inlet and the inside of the quadrupole allowing for highly sensitive gas measurements. The deployments UW-MIMS-3 and UW-MIMS-4 represented gas surveys where instrument parameter settings were kept constant.

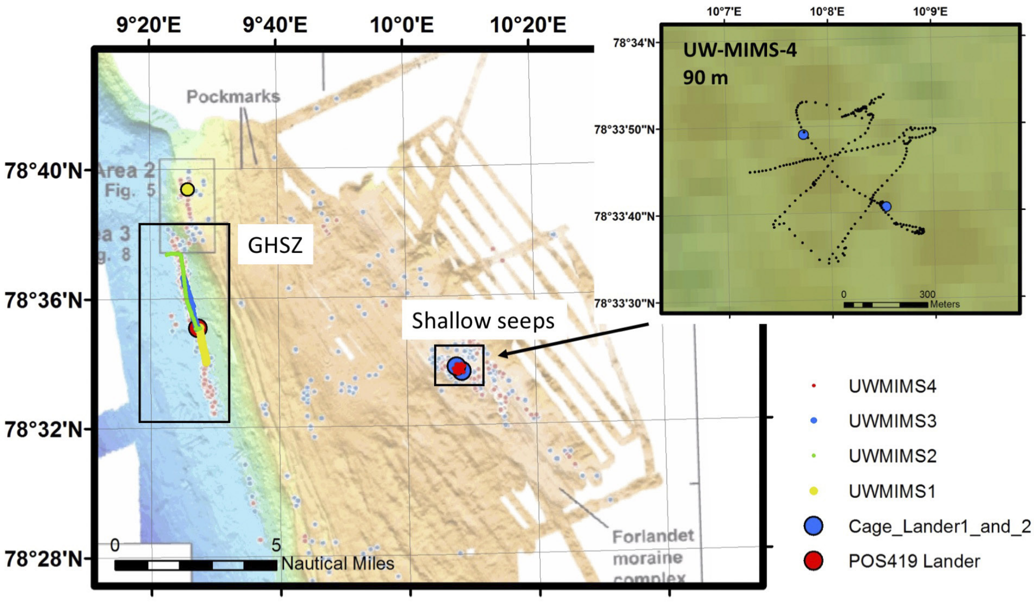

Fig. 3.4.1: Map of the two working areas in the GHSZ and the shallow water seep region, where gas survey were conducted. The insert indicates the track during deployment UW-MIMS 4. POS419 and Cage Lander refer to previous studies.

The distribution of gases (CH_4, pCO_2, N_2, Ar) were continuously and simultaneously recorded using the UW-MIMS which was deployed in combination with two separate sensors for the measurement of pCO_2 and CH_4 (HydroC CO_2, HydroC CH_4, both from Kongsberg Maritime subsea), temperature-, pressure-, and pH-sensor as well as a camera system for seafloor imaging. A glass fibre telemetry developed at GEOMAR allowed online transfer of video and sensor data as well as for the complete online operational control of the mass spectrometer. The system was towed above the seafloor in about 1 to 1.5 m distance. The towing speed was maximum 0.5 kt. Parallel to the gas measurements the ship GPS position as well as the hydro-acoustic signal for flare imaging was logged on separate computers and will be combined with gas measurements.

The set-up of the UW-MIMS is based on a quadrupole mass spectrometer (Prisma QMG 220) in combination with a closed high sensitivity ion source. The instrument includes an ion getter pump, which was only used during the test surveys UW-MIMS 1 and 2. During the actual gas surveys UW-MIMS-3 and 4 the vacuum was maintained using the membrane pump and the turbo-pump maintaining a pressure of about 6.1×10^{-6} mbar. A secondary electron multiplier was used to detect the ion currents of the different mass to charge ratios. The gas extraction took place at a membrane inlet using a novel membrane metal sinter combination from Kongsberg with improved permeability. A Peltier cool trap can be used to remove water vapor. During the deployments UW-MIMS-1 and UW-MIMS-2 water flow to the inlet was generated using an underwater peristaltic pump, but upon failure it was replaced by a Seabird pump during the following UW-MIMS deployments. *In-situ* pressure at the inlet was about 0.8 mbar. The UW-MIMS further records the outside water pressure as well as temperature and pH. Data were stored locally on the computer of the MIMS but online access from outside was enabled.

Tab. 3.4.1: Station table of UW-MIMS surveys. The date/time and location at the start and end of the survey is denoted by the first and second row of the respective deployment. GHSZ: Gas Hydrate Stability zone.

Station no.	Gear	Date/time [UTC] start/end	Position start/end	Working Area
PS108_14-1	UW-MIMS-1	28.08.2017 00:53	78°35.12’ N 9°27.83’ E	GHSZ
		28.08.2017 04:15	78°34.05’ N 9°28.69’ E	
PS108_17-1	UW-MIMS-2	28.08.2017 19:50	78°35.08’ N 9°26.98’ E	GHSZ
		29.08.2017 01:53	78°37.37’ N 9°22.60’ E	
PS108_31-1	UW-MIMS-3	01.09.2017 03:38	78°35.08’ N 9°27.26’ E	GHSZ
		01.09.2017 08:33	78°36.62’ N 9°25.26’ E	
PS108_43-1	UW-MIMS-4	04.09.2017 07:07	78°33.64’ N 10°8.62’ E	Shallow water
		04.09.2017 11:48	78°33.79’ N 10°7.12’ E	

Preliminary (expected) results

Beside high-resolution gas distribution mapping across methane seep sites major goal was to test and demonstrate technical functionality of the UW-MIMS system under in-*situ* and ship operation conditions. Hence, the first two deployments were used for tests to obtain optimized pressure conditions inside the MIMS as well as for the set-up of the ion source and the Peltier cooling trap to suppress water vapor. Both deployments showed that the UW-MIMS is working well and low pressure conditions can be maintained during the deployments. Unfortunately, during all deployments and tests in the shipboard laboratory the ion source periodically switched off generating small pressure changes inside the mass spectrometer, which slightly affected the ion current of each mass.

During the deployments UW-MIMS-3 and UW-MIMS-4 the technical settings were kept constant using the membrane- and the turbo pump to maintain the pressure conditions and the Peltier cool trap was switched off. Both deployments were successful recording about 2,284 and 4,958 discrete sample measurements about every 3 s, simultaneously tracking 6 independent chemical parameters in real time. In the following only results from deployment UW-MIMS-3 are shown. During this deployment, the pressure conditions inside the mass spectrometer were stable, however, P2 showed a slight decrease affecting the ion current strength of the different masses (Fig. 3.4.2). The slight fluctuations of the pressure P2 were caused by the instabilities of ion source.

During the survey UW-MIMS-3 and signals of CH_4, pCO_2, Ar, N_2, and water vapor was recorded on the mass to charge ratios 15, 44, 40, 28 and 18 respectively. Despite problems with the ion source stability, signals of all masses could be recorded. The CH_4 signal, after removal of the drift caused by a decrease of the pressure P2 by linear detrending has been clearly resolved (Fig. 3.4.3). Parallel measurements using the Kongsberg HydroC CH4 sensor provided CH_4 concentrations in the range of 75 to 100 ppm indicating that the UW-MIMS was able to resolve 25 ppm, which is similar to an *ex-situ* MIMS system used to map CH_4 concentrations at a blow-out site in the central North Sea (Sommer et al., 2015).

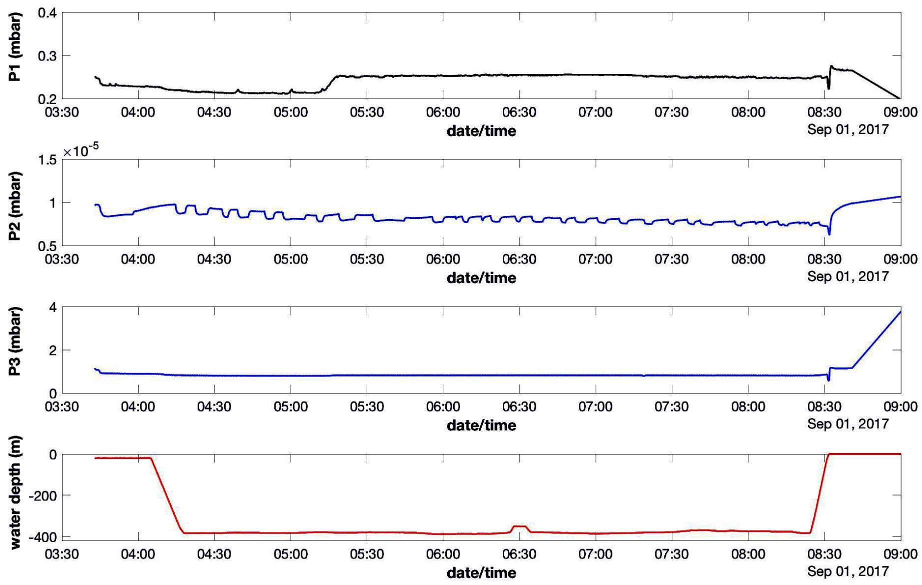

Fig.3.4.2: Pressure conditions inside the UW-MIMS during the deployment 3. Water depth during the gas survey is indicated. P1, P2 and P3 refer to pressure at the membrane inlet, pressure inside the quadrupole and pressure at the membrane pump respectively.

At the end of the gas survey at the shallow water seep site (UW-MIMS-4 PS108-43), tests were conducted to resolve the response- and equilibrium time (t63) of the mass spectrometer. The pump generating the water flow inside the membrane inlet was switched off resulting in a rapid depletion of gases of the enclosed water body. Subsequently, the water flow was switched on and the signal of the different mass to charge ratio reestablished (Fig 3.4.4).

The equilibrium time was 113 s, the corresponding response time T_{63} was 71 s which is about twice times longer than reported for an ex situ mass spectrometer used for methane mapping (Sommer et al., 2015) but comparable to the in-situ system from Schlüter et al (2008). The signal noise was about 3.4 10^{-14} A, which corresponds to approximately 18 % of the CH_4 concentration range of 180 ppm measured by the parallel Hydro C CH_4 sensor, resulting in a detection limit of about 32 ppm. At a maximum towing speed of 0.5 kt this corresponds to a spatial resolution of 29 m.

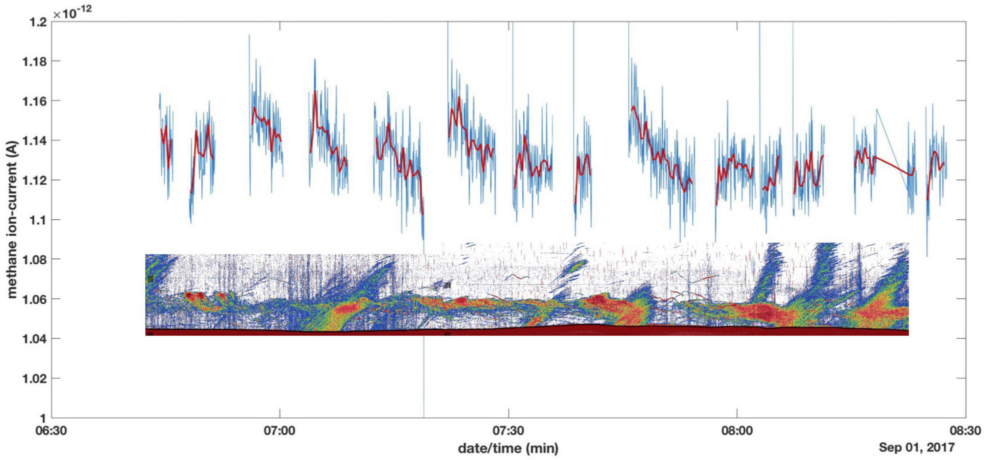

Fig. 3.4.3: CH_4 measurements across seep sites off Spitsbergen (UW-MIMS-3 PS108_31) Insert shows the gas flare almost reaching to the sea surface. Gas flares were recorded with the shipboard SIMRAD-Kongsberg EK60 echosounder (38, 70, 120, 200 kHz).

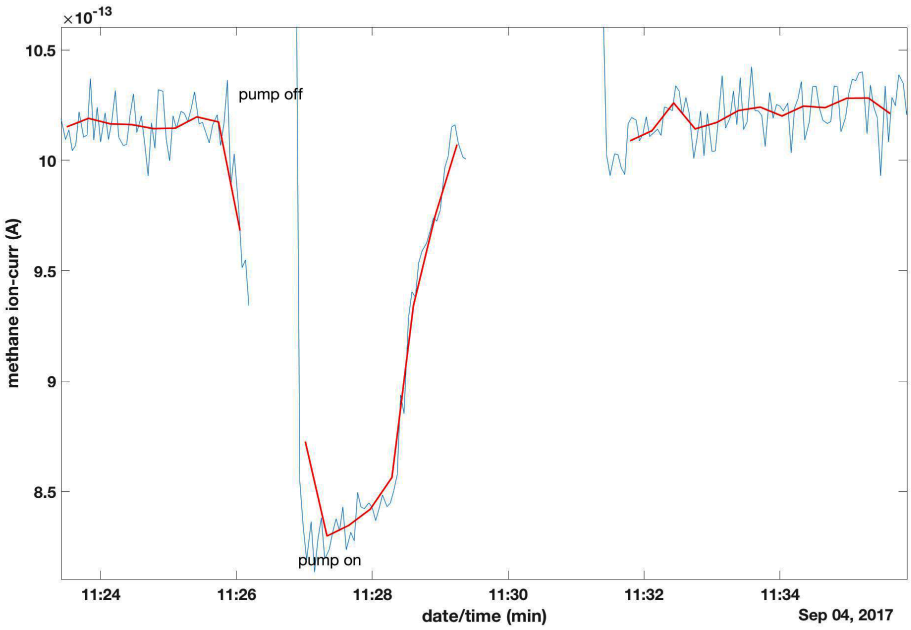

Fig. 3.4.4: Determination of the equilibrium and response time (t_{63}) for CH_4 at the end of survey UW-MIMS-4 (PS108_43) during tests switching the flow across the membrane of the inlet off and on.

The first *in-situ* deployments of the GEOMAR UW-MIMS were successful and the spatial variability of the bottom water CH_4 concentration at two seep sites could be resolved. The response time of the instrument was fast and allows for relatively high spatial resolution during gas measurement surveys. This and the simultaneous detection of various volatiles represent a major advantage of this system in comparison to commercially available single parameter gas sensors. The instrument appeared to be very robust even against mechanical shocks during deck operations. The instability of the ion source and its sensitivity against noise in shipboard electric system and possibly by instrument itself needs to be improved.

Data management

All data produced during the UW-MIMS survey will be stored at GEOMAR. On request they will be made accessible to all project participants by Dr. Stefan Sommer (GEOMAR). Data obtained during the UW-MIMS surveys 3 and 4 will be prepared for publication.

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3.5 Autonomous Underwater Vehicle (AUV)

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Grant-No. AWI_PS108_00

Objectives

Starting in 2008 / 2009 the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) has regularly operated its Autonomous Underwater Vehicle (AUV) “PAUL” to investigate biogeochemical processes in the upper water column. After 2013, understanding the interaction between physics and biology in highly stratified waters, such as frontal systems or marginal ice zones (MIZ), has become the main objective of the AUV project.

With its PS 108 deployments, the AUV continued this series of investigations, yet, compared to the previous years, the AUV programme had a stronger focus on under-ice work. With regard to ROBEX, the objective was to conduct simultaneous missions both below and above the ice using autonomous robots and a helicopter. With the AUV gathering biogeochemical and physical data below the ice, an unmanned aerial vehicle (UAV) and *Polarstern´s* helicopter would collect data on the ice´s drift speed, its surface topography and the light intensity on the ice (detailed description of planned UAV-operations, see following chapter 3.6).

To understand the dynamics of the MIZ, the AUV carried an extensive payload consisting of biogeochemical sensors, such as a nitrate sensor, a chlorophyll a fluorometer, a dissolved oxygen sensor, and a fluorometer for colored dissolved organic matter (CDOM). Along with the vehicle´s water sample collector, these instruments would measure the distribution of nutrients and phytoplankton biomass. An upward looking radiometer measuring irradiance between 400 – 700 nm (photosynthetically active radiation, PAR) provides a detailed light profile and the location of the euphotic zone. In addition to that, the physical oceanography package on the vehicle comprised upward and forward looking microstructure probes, measuring the fine scale distribution of temperature and velocity shear to provide information on mixing processes, an upward looking 300 kHz acoustic doppler current profiler (ADCP) and a conductivity, temperature, depth probe (CTD).

The objective was to cover transects of several kilometres length perpendicular to the ice edge and its associated meltwater front. As the transect would have to start below the ice and then reach out into open water, the vehicle needs to reach its starting point below the ice, make a 180° turn and commence the transect. During the transect the AUV constantly varies its mission depth between 53 and 10 m depth in a “sawtooth” shaped pattern (Fig. 3.5.1). Every 1,000 m, the vehicle would also switch off its thruster to start a vertical ascent towards the ice/ surface (Float maneuver). Both maneuvers will help resolve the vertical stratification of the water column.

In addition to the dives, the AUV team applied an underway-CTD, ship’s ADCP and the ship´s thermosalinograph to investigate frontal systems. Although these investigations were planned to support AUV operations, weather conditions made it impossible to run larger instruments for some time of the expedition and an unexpected amount of time could be assigned to this task. These investigations thus became an individual topic during the cruise. For detailed information please see chapter 5.

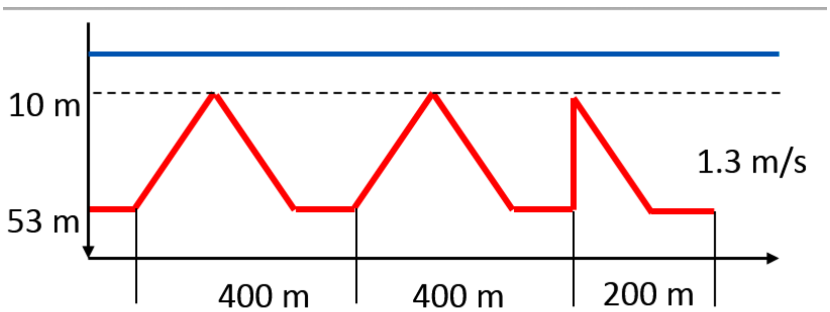


Fig. 3.5.1: Basic part of the AUV´s mission: The entire mission consisted of nine of these 1,000 m long parts which are executed consecutively.

Consequently, there were scientific and technological objectives during PS108:

- Cover transects of several kilometres length to resolve the structure of the water column in the MIZ.
- Successfully operate different (autonomous) platforms to gather a holistic dataset of the environmental conditions in a MIZ.
- Determining relevant ice related parameters such as drift velocity, direction of drift and surface topography.

Work at sea

During expedition PS 108 the AUV conducted two dives (Fig. 3.5.2).

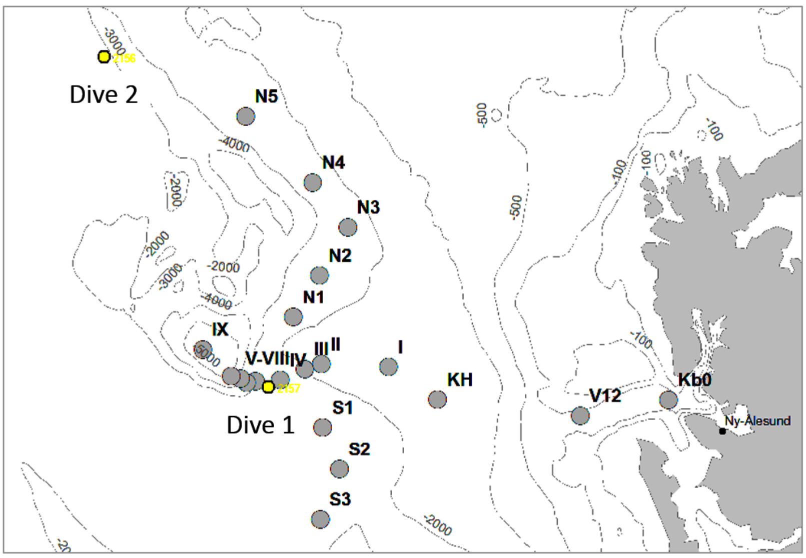


Fig. 3.5.2: Map of the Hausgarten stations showing the locations of the two dives

- Dive 1 (Dive ID: 037, 27.08.17)

The first dive was planned to be a combined test and scientific dive. Using Polarstern´s thermosalinograph, a promising region between HG IV and V featuring structures of the

Polarfront was selected. It was planned to completely run the later under-ice mission to gather a cross section through the frontal system and to collect water samples for calibration purposes. However, the dive was largely hampered by a communication issue between the control container and the vehicle. During the alignment, communication was lost and could not be reestablished until the vehicle was recovered and reset manually. Another transmitting device on the ship likely caused the issue.

After the manual reset, the test continued successfully yet needed to be shortened due to time constraints. Running three short missions with a max. depth of 80 m, basic vehicle functions such as its angle of attack during ascent and descent, its stability during the float maneuver and a “descent spiral” were tested (Fig. 3.5.3).

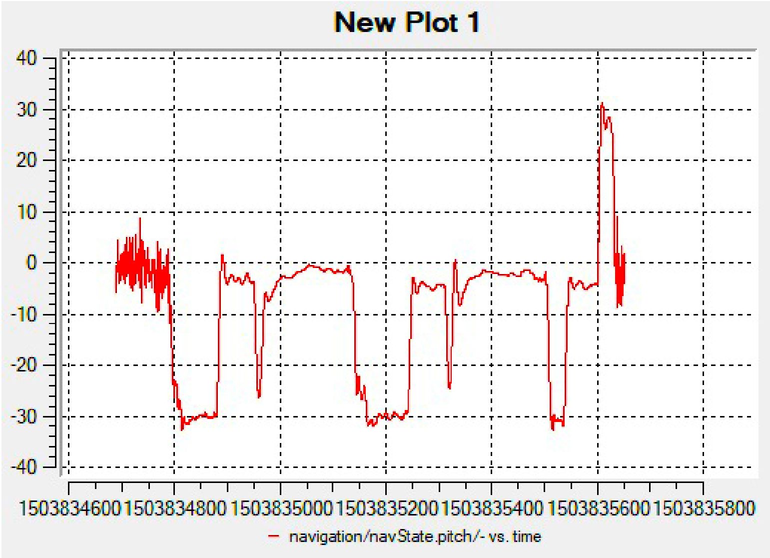


Fig. 3.5.3: Exemplary plot of pitch angle vs. time. The blue arrows indicate two periods of 4 minutes duration each with the vehicle maintaining a constant -2° pitch during a Float maneuver.

Trimming of the vehicle turned out to be correct and the vehicle had no problems diving (which was problematic during PS 99 in 2016). All vehicle systems including the payload performed well but the under-ice mission could only be executed partially.

- Dive 2 (Dive ID: 038, 30. / 31.08.17)

For the second dive, an ice field featuring app. 15 % ice concentration (based on Satellite information) and reaching southwards from 80° 45´ N to the Molloy Deep region was investigated in detail. A large ice floe was selected as the principal target of the AUV´s under ice dive (Fig. 3.5.4). Prior to the AUV dive, 6000 aerial pictures were taken of the surface of the floe. Additionally, the Landing UAV of the University of Würzburg was tested on the ice for the first time. During these tests, the Landing UAV, the groundstation as well as control computers were damaged by a low pass of one of *Polarstern´s* helicopter and was unavailable for the under ice mission.

The ice floe started to disintegrate shortly after *Polarstern´s* arrival and pieces of ice were quickly drifting apart. The ice conditions were observed using radar. AUV mission parameters such as its starting and recovery point were defined using drift estimates derived from *Polarstern´s* radar systems.

After a short initial test, the AUV dived towards its first waypoint about 1,000 m behind the ice edge in 53 m water depth. As expected, the acoustic tracking signal was lost during this phase of the dive as the AUV was pointing its thruster towards *Polarstern*. At the waypoint, the AUV turned towards heading 225° – locking onto the "sawtooth"-transect´s general orientation. The transect´s length was about 9 km with the first 1 – 1.5 km below the ice.

The AUV surfaced after about 3 h. During the entire time, the vehicle was exclusively dependent on its inertia navigation system (INS).

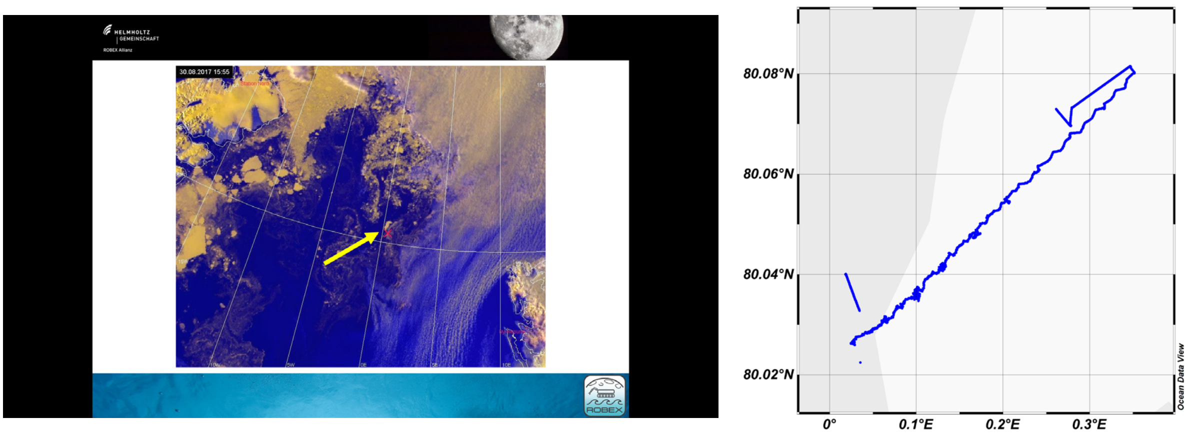


Fig. 3.5.4: (left) Satellite image of the ice floe the AUV was aiming at for its 2nd dive. (right) Map of the AUV dive. The grey line represents the ice edge with the ice in the northeast.

Preliminary (expected) results

To the date this report is written, most of the data are still being processed. The following Figs (Fig. 3.5.5) show two raw physical parameters (temperature and conductivity) and raw voltage data of the CDOM, Chl. *a* and dissolved oxygen sensor to give a qualitative illustration of the biological response.

Conductivity and temperature data indicate a highly stratified water column characterized by low saline meltwater of -1°C at the surface and more saline yet colder water at greater depth. Starting at a section distance of about 1 km, the vehicle left the ice and reached open water. With increasing distance from the ice edge, Chl. *a* fluorescence values seem to increase as well, yet remained relatively low. The fluorescence maximum is located at about 20 m water depth. Following the fluorescence signal, the oxygen distribution reaches its maximum at 20 m water depth as well – indicating a population of living phytoplankton. CDOM data illustrate a wide zone of elevated values reaching from 20 to 50 m water depth. Above and below this zone, CDOM values decrease.

An interesting feature can be seen at 30 – 50 m water depth at section distance 0 - 1 km. Compared to the surrounding water masses, a more saline, warmer water body featuring higher Chl. *a*, higher oxygen concentration yet lower CDOM values can be identified at this location.

From a first check of the ADCP and turbulence data obtained by the AUV it looks as if everything worked as planned. Fig. 3.5.6 shows raw ADCP data gathered by the AUV.

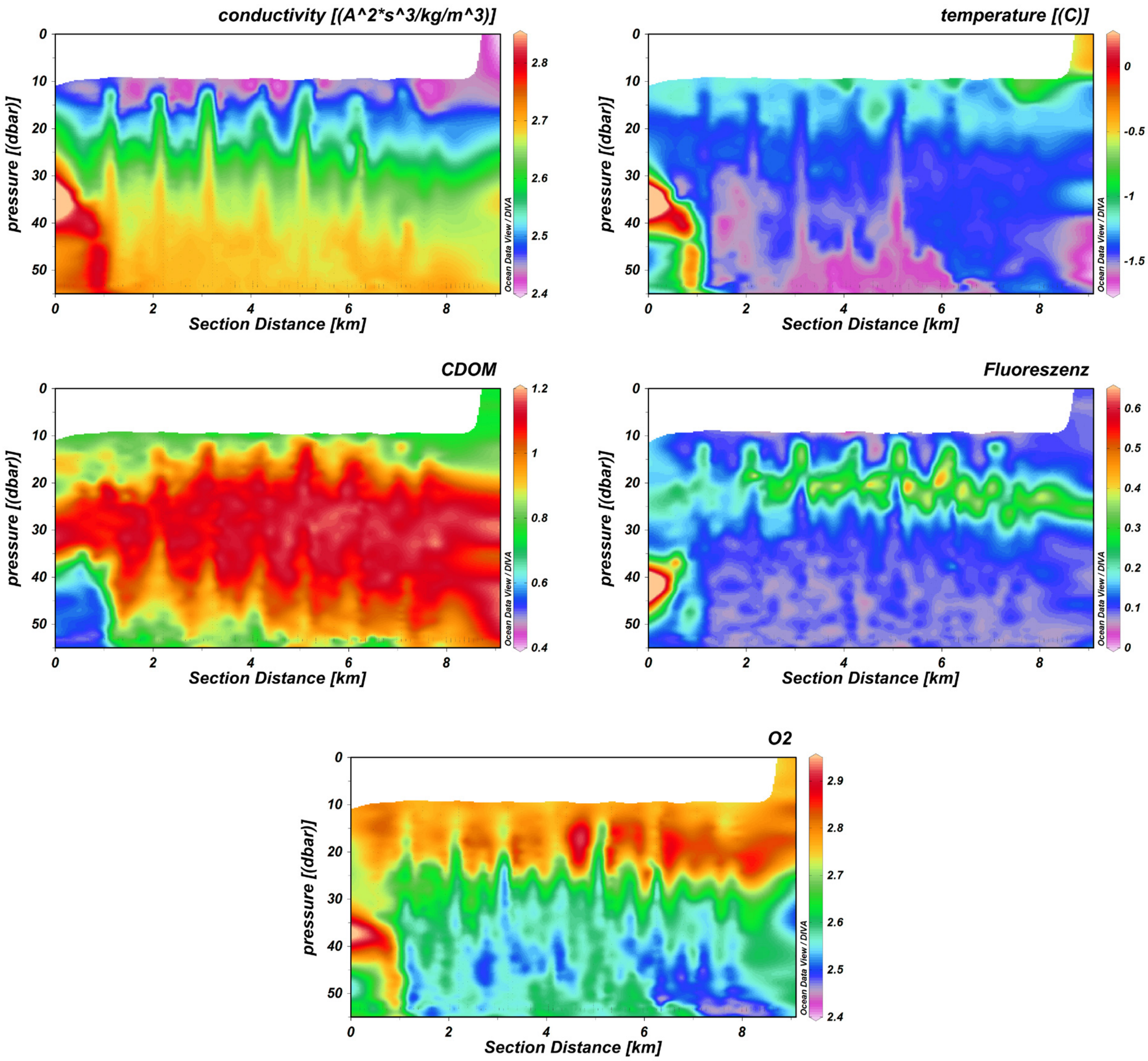


Fig. 3.5.5: (top row left) Conductivity in [S/m] along the transect, (top row right) temperature in [°C], (middle line left) CDOM in raw sensor units [V], (middle line right) Chl. a distribution from fluorescence in raw sensor units [V], (lower line) dissolved oxygen in raw sensor units [V]

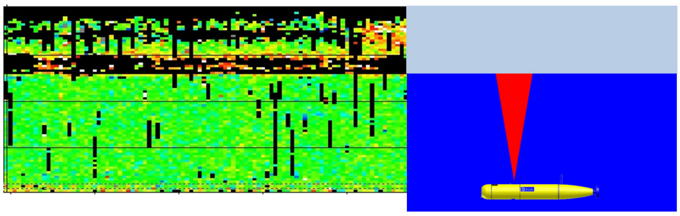


Fig.3.5.6 a: Raw ADCP data gathered in open water. The water surface is depicted as a straight line.

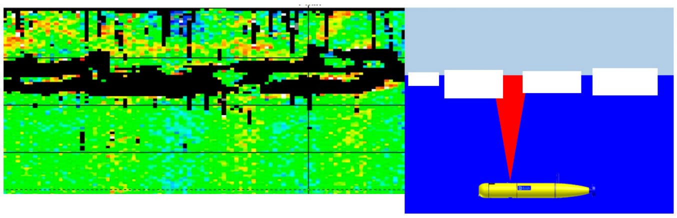


Fig. 3.5.6 b: Raw ADCP data gathered in ice covered water. The underside of the ice is depicted as a wavy line.

As the ADCP is mounted in an upward looking configuration, there was a clear difference between data collected in open water and data collected as the vehicle was travelling below the ice. The straight line in Fig. 3.5.6a represents the echo of the water surface. The signal originating from the underside of the ice is illustrated by a wavy line in Fig. 3.5.6b.

Data management

Processing the data of the several types of instruments will be differently time-consuming. The time period from post processing to data provision will vary from three months for data such as fluorescence and dissolved oxygen to nine months for microstructure and ADCP data. Until then preliminary data will be available to the cruise participants and external users after request to the senior scientist. The finally processed data will be submitted to the PANGAEA data library. The unrestricted availability from PANGAEA will depend on the required time and effort for acquisition of individual datasets and its status of scientific publication.

3.6 Unmanned aerial vehicles (UAV)

Michael Strohmeier[1], Julian Rothe[1], Thorben Wulff[2], Sascha Lehmenhecker[2] (not on board)

[1]Uni Würzburg
[2]AWI

Grant-No. AWI_PS108_00

Objectives

Within the Helmholtz Alliance for Robotic Exploration of Extreme Environments (ROBEX) small unmanned aerial vehicles (UAVs) are developed to support the autonomous underwater vehicles (AUV) PAUL during explorations below Arctic sea ice.

In order to operate AUVs successfully at the marginal ice zone (MIZ), it is crucial to keep track of the permanently moving ice edge. By deploying GPS-based tracking systems on the ice edge, the ice drift can be observed before and during AUV operations. However, the manual deployment of tracking systems is dangerous and time consuming. Therefore, starting in 2014, the University of Würzburg together with the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) began to develop UAVs that can fly autonomously in polar regions and are able to land on ice shores.

While a variety of consumer grade and professional solutions for autonomous drone exists, the Arctic environment is still a challenge for small autonomous UAVs. One critical aspect is a reliable heading estimation despite the weak horizontal component of the Earth's magnetic field at high latitudes. Initial flight tests during PS99.2 in 2015 showed that autonomous flights based only on magnetic navigation are possible at latitudes below 78°N and not within ship vicinity. To overcome this limitation, a Differential GPS (DGPS) heading estimation system based on two GPS receivers and real-time kinematics, was implemented to determine the orientation of the UAV at higher latitudes and within ship vicinity.

Furthermore, in order to communicate with the UAV during flight operation a special UAV ground station was developed for receiving telemetry and video data and transmitting commands in real-time.

Consequently, the main technological objectives during PS108 were to:

- Investigate the UAVs navigation and flight capabilities at high latitudes and in ship vicinity
- Integrate the UAV ground station into existing ship and AUV infrastructure and evaluate its functionality
- Demonstrate a complete AUV/UAV mission

Additionally, as a scientific objective during the common AUV/UAV mission, the UAV carried a sensor in order to sample the photosynthetically active radiation (PAR) on ice as reference data for the measurements conducted simultaneously by the AUV under the ice.

Work at sea

During expedition PS108 several experiments in order to validate the UAV's flight capabilities at high latitudes as well as in ship vicinity were conducted. Unfortunately, due to unforeseen events during the on-ice Test and poor weather conditions a full demonstration mission together with the AUV could not be executed.

- Preflight system checks and ground station

Prior to the first AUV Dive, a full system and sensor suit checks were performed. Both, the UAV as well as its ground station, had difficulties to estimate a reliable heading using DGPS. Otherwise, both systems were fully functional. The real time data of the UAV was successfully integrated into the AUV planning tool.

- AUV Dive 1 (Dive ID: 037, 27.08.17)

The first AUV dive was planned to be a full AUV/UAV mission simulation. Since no suitable ice floe for landing was available during this dive, the UAV was only required to fly manually in ship vicinity. During the mission, the GPS Tracker used to track the position of the Zodiac for deployment and recovery of the AUV interfered with the communication link between the ground station and the UAV. Since communication problems occurred simultaneously between the AUV and its container, the UAV part of the mission simulation was cancelled. Interference between the UAV communication link and the Zodiac GPS trackers could be confirmed and a work around solution found. However, the AUV communication problem could not be reproduced. Despite the communication problem and the unstable DPGS heading all systems including the PAR payload sensor performed well.

- Flight Test 1 (28.08.17)

Since the originally planned flight test during the AUV/UAV mission simulation could not be conducted, the first flight test was carried out on the day after the AUV dive. The UAVs position was controlled manually and several takeoffs and landings were conducted on the helicopter platform. The system's takeoff, landing and height control using a barometric pressure sensor and downwards pointing laser distance sensor were successfully tested. The total air time was about 10 minutes.

- On-ice Test and AUV Dive 2 (Dive ID: 038, 30. / 31.08.17)

The second AUV Dive was planned to be a full mission demonstration at 80° 45' N. Prior to the AUV dive, additional UAV experiments had to be conducted on ice. Since there were problems with the DGPS heading estimation in ship vicinity, it had to be evaluated whether an autonomous flight using magnetic navigation was possible at 80°N. Additionally, it had to be evaluated whether the DPGS heading system was working on ice and therefore whether signal interferences due to the ship were the main cause of the afore mentioned DGPS problems.

During a first helicopter exploration flight, aerial pictures of a large ice floe were taken and suitable locations for the second AUV dive as well as the UAV on-ice test selected. A second helicopter flight was needed to transport the UAV and the required parts of the ground station equipment onto the ice. Due to technical reasons the helicopters had to be swapped between the exploration and the ice landing flight which caused an unexpected delay.

On the ice floe several test flights were conducted and the relevant data recorded. The tests indicate that an autonomous flight at 80°N with a magnetic reference sensor are not possible. Although a magnetic heading could be obtained, the magnetic field measurements were heavily disturbed by the UAV motors. An autonomous flight would have been therefore not possible at 80°N. However, the UAV could have been operated manually during the AUV/UAV mission demonstration.

Since other experiments were supposed to be conducted and a camera team had to be available for the documentation of the work on the ice floe, the helicopter delivered a second group of people onto the ice. Subsequently, the UAV as well as other electronic equipment got damaged during a low helicopter pass. The barometric pressure sensor which is used for a controlled altitude flight was unable to obtain valid height information. Additionally, the PAR payload sensor did not show any valid measurements anymore.

After drying all electronic components on the ice, the UAV could be fixed and was airborne again. Unfortunately, precious time on the ice was lost because of this incident and there was no time to evaluate the DGPS heading on ice properly.

Back on the ship, the UAV participation in the full AUV/UAV mission demonstration had to be cancelled, since there was not enough time to run a full UAV system check before the AUV dive and permanent damages could not be excluded.

- Flight Test 2 (31.08.17)

The UAV was checked for permanent damages after the incident on ice. After all critical components seemed to work again, the UAV was successfully tested on the helicopter platform of the ship.

- DGPS Test 1 (03.09.17)

The little data gathered on the ice regarding the DGPS heading indicated, that a valid heading could be obtained if good enough GPS signal were received. After a quick test indicated that our spare, commercial GPS receivers had a slightly better Signal-To-Noise ratio (SNR) than the ones used on the UAV platform. The commercial receivers were integrated into the UAV and subsequently two experiments conducted. Fig. 3.6.1 shows the first setup.

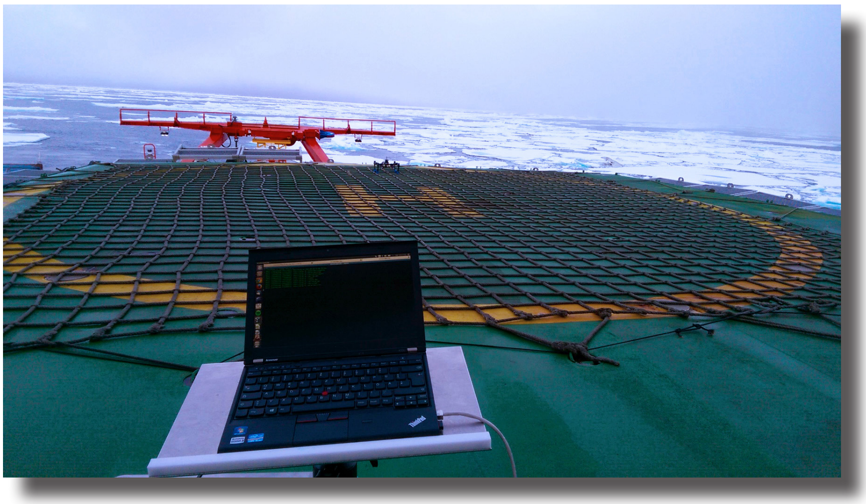


Fig. 3.6.1: The UAV on the helicopter platform during the first experiment

During the first experiment the UAV was aligned with the ship and collected data for 10 minutes while standing on the helicopter platform. During the second experiment the UAV was aligned with the ship and standing on the helicopter platform for 5 minutes. Subsequently, the UAV was carried in a specific pattern across the helicopter platform. Afterwards, the UAV was aligned with the ship again. For both experiments, a valid DGPS heading could be obtained.

- DGPS Test 2 (04.09.17)

In order to evaluate the DGPS heading over a longer period within ship's vicinity another experiment was conducted. The UAV was aligned with the ship and placed on the helicopter platform. The ship followed a predefined path in the shape on an 8 as shown in Fig. 3.6.2.

The UAV recorded the GPS raw data for almost 2 hours while the ship's heading was simultaneously logged as a reference. Conversely than on the previous day, landers were standing on the helicopter platform and the A frame was up as shown in Fig. 3.6.3. The GPS signal might have been disturbed or reflected by the surrounding metal.

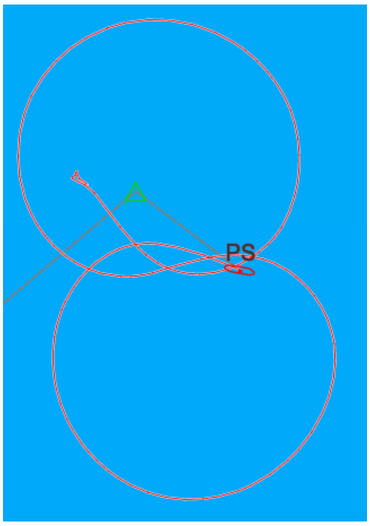


Fig. 3.6.2: The predefined track

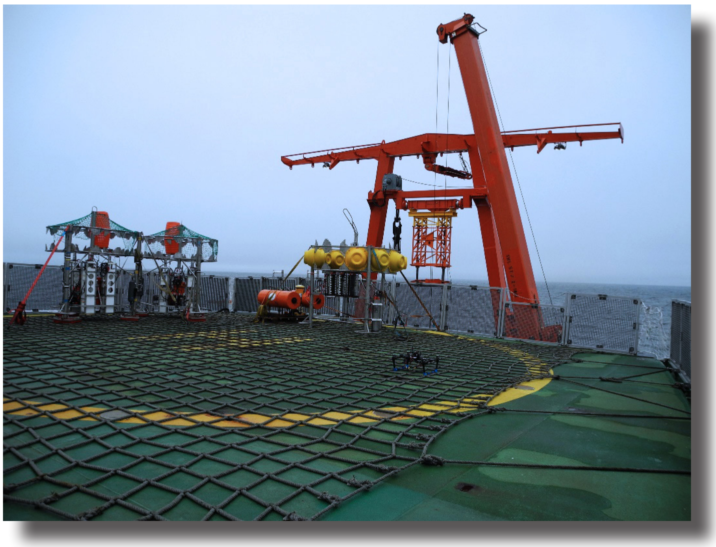
Preliminary (expected) results

As afore mentioned, due to unforeseen events during the on-ice test a full mission demonstration together with the AUV could not be performed and therefore one of the main technological objectives as well as the scientific objective could not be met. Due to poor weather conditions, the full mission demonstration could not be re-scheduled either.

To the date this report is written, not all the collected data is analyzed and processed yet. Especially the data collected during the DGPS Test 2 experiment needs extensive evaluation. The results so far indicate, however, that in general an autonomous flight in the ship's vicinity using DGPS is possible if the acquired GPS signals have a good SNR and are free from multipath. Fig. 3.6.4 shows the satellite elevation and their azimuth for one GPS receiver during 2 hours. In contrast to measurements conducted in Europe, there are no satellites available with an elevation higher than 60°. Since the SNR increases with the satellite elevation, it is crucial to reduce the receiving noise as far as possible in order for DGPS to work. The according relation between SNR and elevation is shown in Fig. 3.6.5.

Especially the data collected during the DGPS Test 1 support the hypothesis that an autonomous flight is possible if the received GPS signals have a high SNR and low multipath. Fig. 3.6.6 shows the result of the second experiment during DGPS Test 1.

Fig. 3.6.3: The UAV during the 8 experiment



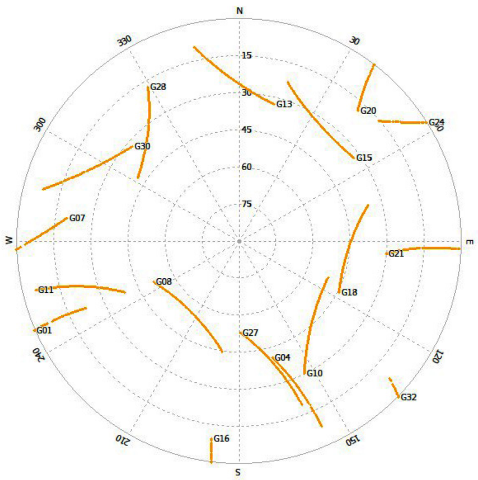


Fig. 3.6.4: GPS Azimuth and Elevation during 2 hours at 79°N and 8°E

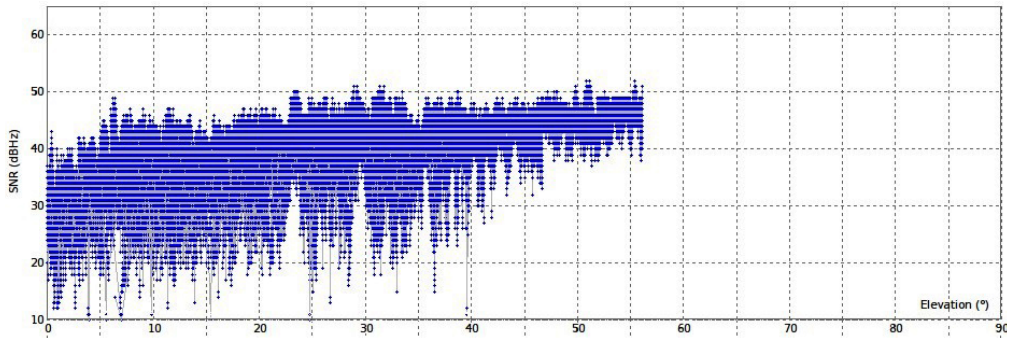
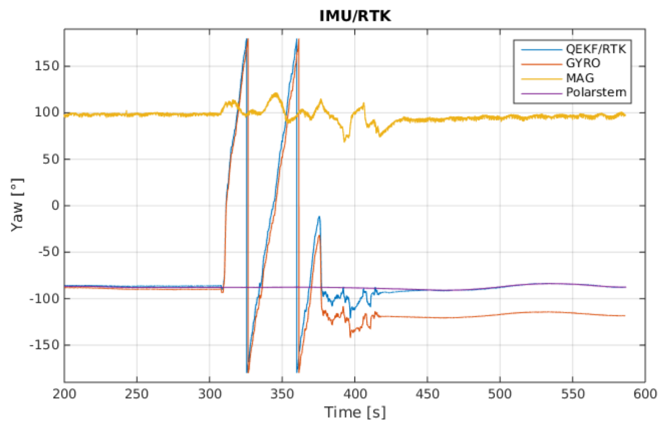


Fig. 3.6.5: SNR vs elevation for GPS satellites during 2 hours at 79°N and 8°E

Fig. 3.6.6: Second experiment during DGPS Test 1



In the beginning, both the DGPS heading (QEKF/RTK) and the gyroscope heading (GYRO) are identical to the ship's heading (*Polarstern*). The magnetic heading (MAG) estimation is during the whole measurement wrong, since the Earth magnetic field is heavily disturbed by the ship. After the UAV is moved between t=300s and t=450s, the gyroscope heading has an error of approximately 40°, while the DGPS heading aligns and coincides with the ship's heading again.

Data management

Not applicable.

4. HAUSGARTEN – BIOLOGICAL LONG-TERM EXPERIMENTS, MEGAFAUNA OBSERVATIONS AND LITTER OBSERVATIONS

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Kirstin Meyer[2]; Mine B. Tekman[1], Lars Gutow[1], Gunnar Gerdts[1] (not on board)

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Grant-No. AWI_PS108_00

During *Polarstern* expedition PS108, the Remotely Operated Vehicle (ROV) KIEL 6000 was used to sample previously established biological *in-situ* long-term experiments in 2,500 m water depth at the central HAUSGARTEN site HG-IV (Fig. 4.2). In addition, a towed photo/video system was deployed along given transects to study large-scale distribution patterns of epi/megafauna organisms and human debris at the deep seafloor.

Please note that "Data Management" is listed at the end of subchapter 4.4 for the whole chapter 4.

4.1 The dropstone experiment

Grant-No. AWI_PS108_00

Objectives

There is abundant evidence that habitat structures have important effects on spatial distribution patterns of meiofauna populations in deep-sea environments (Hasemann et al., 2013). A common feature in polar deep-sea regions is the occurrence of dropstones at the deep seafloor, which enhance topographic heterogeneity and alter related hydrodynamic patterns. Changed flow regimes around dropstones can have a direct effect on the colonisation and settlement of meiofauna individuals, and indirect effects on meiofauna communities by the amount of potential food trapped around dropstones and changing sediment characteristics.

To study community patterns in nematodes (i.e. the dominant metazoan meiofauna group in deep-sea sediments) in relation to altered flow regimes and patchy food availability, artificial dropstones with different shapes (cylindrical, hemispherical and cuboidal; approx. 40 cm in diameter, 10 cm in height; Fig. 4.1.1) were deployed by means of a video-guided launcher system at 2,500 m water depth during the *Polarstern* expedition PS99.2 in summer 2016 (Fig. 4.1.2). The stones were deployed roughly in a line along the main current direction (which is to the North-West at about 5 cm s^{-1}) with distances of approx. 10-15 m to each other.

Fig. 4.1.1: Artificial dropstones and cylindrical homer beacons for tracking the stones at the deep seafloor laid out in a workshop before shipment

Work at sea

Initial sediment sampling around the dropstones took place during this year's *Polarstern* expedition PS108 using the ROV KIEL 6000. Two sediment cores were taken at each dropstone. In relation to the main current direction, one core was taken in "luv" of the stone and the second one in "lee" of each dropstone. Additional four sediment cores, taken from nearby undisturbed sediments serve as controls.
The uppermost five centimetres of the sediment cores were sub-sampled to analyse parameters like plant pigments, fluorometrically analysed as Chloroplastic Pigment Equivalents, CPE (indicating the input of organic matter from phytodetritus sedimentation), organic carbon, lipid, and proteins contents (indicating benthic biomass), sediment granulometry, and the sediment-inhabiting biota (i.e. bacteria, meiofauna). Most of the sub-samples were stored for later analyses at the home lab. Chloroplastic pigments have been analysed onboard.

Preliminary results

First results indicate an impact of the dropstones on the distribution of potential food around the stones already one year after their deployment. We found significant differences in CPE contents of the sediments in relation to the position sampled around the dropstones, also in relation to the different shape of the dropstones. Sediment-bound pigment concentrations behind the roundish dropstones (cylinder and hemisphere) were higher compared to those found in sediments in front of these stones. In contrast, CPE contents in sediments behind the squared (cuboid) dropstones were lower compared to the sediments in front of that specific stone (Fig. 4.1.3).

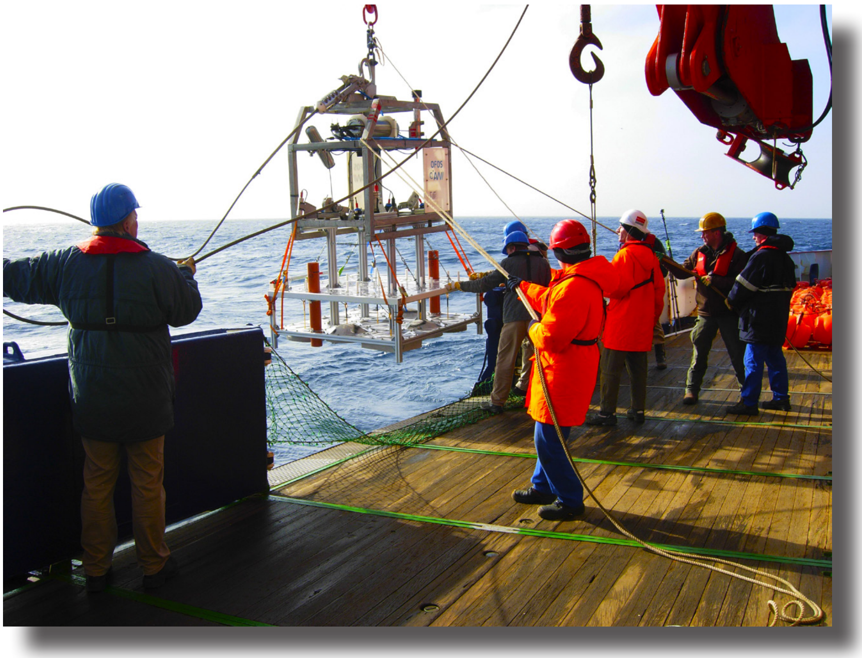

Fig. 4.1.2: Deployment of the artificial dropstones using a video-guided launcher system during Polarstern cruise PS99.2 in summer 2016

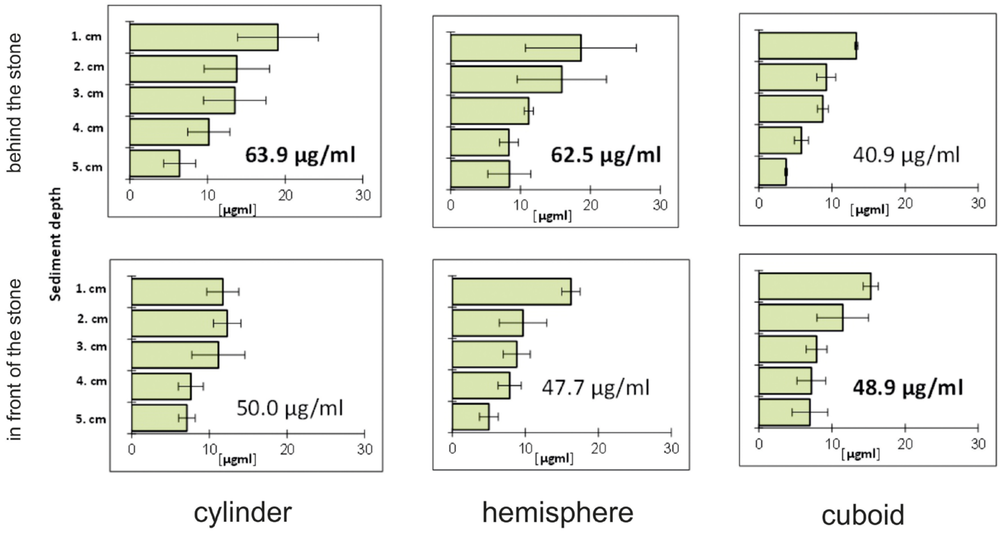

Fig. 4.1.3: CPE contents (mean values and SDs from replicates) within the uppermost five centimetres of the sediments in front of and behind the different shaped dropstones.

4.2 The colonisation experiment

Grant-No. AWI_PS108_00

Objectives

The HAUSGARTEN contains not just soft sediments but also hard substrata, including a steep rocky reef at station „Senke“ (Meyer et al., 2014) and dropstones at many stations (Meyer et al., 2016). Hard substrata are colonized by sessile (soft corals, anemones, sponges, and crinoids) and mobile (shrimps, amphipods) invertebrates (Schulz et al., 2010; Bergmann et al., 2011; Meyer et al., 2014, 2016). While hard-bottom communities are readily observed with underwater imagery, until now very little was known about how these communities form or develop over time.

A long-term experiment was begun at the central HAUSGARTEN station in 1999 to study the development of deep-sea hard-bottom communities in the Fram Strait. A metal frame was deployed on the seafloor with 46 attached settlement plates made from plastic, stone, and wood (Fig. 4.2.1). Growth on the plates would show which species recruited first to substrata and in what abundance, differences in recruitment between natural and anthropogenic substrata, and how quickly Arctic deep-sea species grow. The frame was visited in 2005 and 2011 with a ROV, and in 2005, seven of the plates were cut off and recovered. The wood panels were not visible in past ROV videos and are thought to have washed off during deployment. During PS108, the time-series experiment was brought to an end and the frame recovered.

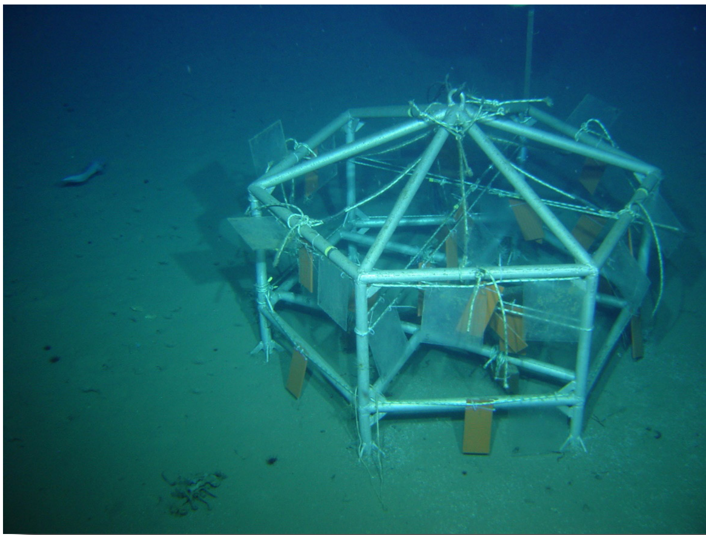

Fig. 4.2.1: Metal frame with different kinds of hard substrates deployed in 1999 at the central HAUSGARTEN site HG-IV

Work at sea

The long-term settlement experimental frame was recovered from the seafloor on 31 August, 2017, using ROV KIEL 6000. The ROV first descended to the seafloor, located the experiment, and then attached a line from the ship’s winch to the top of the settlement frame. The frame was raised from the seafloor at 0.3 m s^{-1} in order to prevent the inhabitants from washing off.

Once on surface, the frame was brought onto the deck of the ship. MB, CK, and KM photographed the frame, recorded the location of each remaining plate, removed plates from the frame, and saved them for later analysis. Plates were designated as „bottom“ (for plates on the outside of the frame, suspended from the bottom metal row), „top“ (for plates on the outside of the frame, suspended from the top metal row), or „inside“ (for plates on the inside of the frame, suspended halfway between the top and bottom rows. The „bottom“ and „inside“ plates were saved in plastic bags filled with 100% ethanol in the laboratory, while the „top“ plates were saved in a water-filled bin secured on the deck of the ship.

KM counted and identified the inhabitants of each settlement plate on board *Polarstern*. „Top“ plates were analysed first, followed by „bottom“ and „inside“ plates. Voucher specimens of each species were saved in 2 mL vials with 100% ethanol. For *Bathycrinus carpenterii* and *Cladorhiza gelida*, every individual was saved so that their sizes can be measured later.

Preliminary results

A total of 15 species were discovered living on the settlement panels. The most common species were calcareous snd agglutinating foraminiferans, a serpulid polychaete, a thecate hydroid, the crinoid *Bathycrinus carpenterii*, and the sponge *Cladorhiza gelida* (Fig. 4.2.2). For statistical analysis, the abundances of each species on stone plates were doubled to account for the fact that stone plates were half the size of plastic plates.

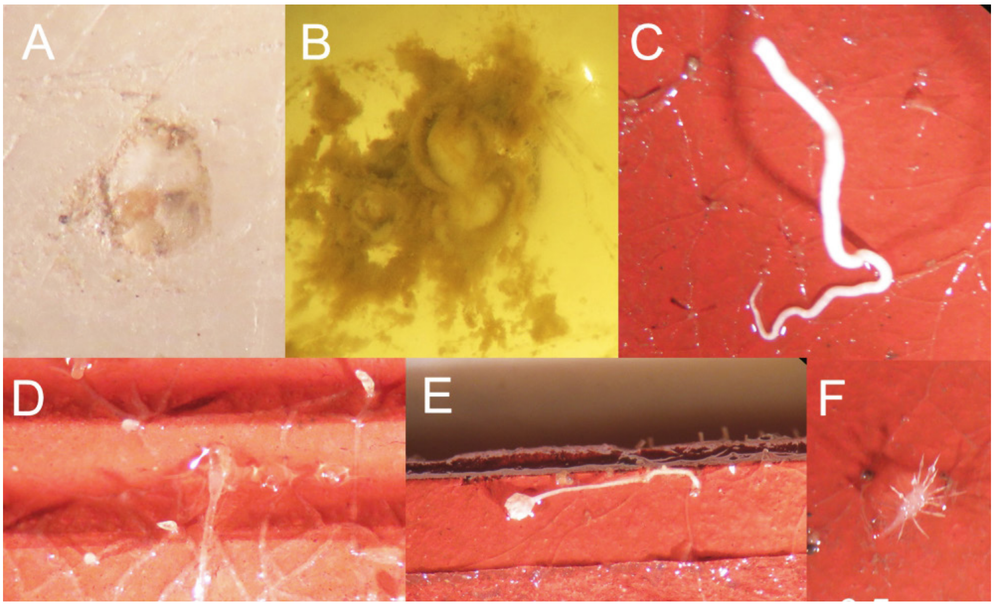

Fig. 4.2.2: Common species on the settlement lander plates. A, Calcareous foraminiferan; B, Agglutinated foraminiferan, photographed from underneath through a clear plastic plate; C, Serpulid polychaete; D, Thecate hydroid; E, Bathycrinus carpenterii; F, Cladorhiza gelida

There were significant differences in the recruits between settlement plates made of different materials (ANOSIM, $R = 0.448$, $p < 0.001$) and at different positions ($R = 0.761$, $p < 0.001$) (Fig. 4.2.3). There were also significant differences in recruits on the front (smooth) side of stone plates versus the back (rough) sides ($R = 0.212$, $p < 0.001$). These differences can be attributed to variable abundances of the most common species. There were more individuals on stone plates (once area was accounted for) than on plastic plates. There were also more calcareous foraminiferans and serpulid polychaetes on plates closer to the seafloor, while hydroids, *Bathycrinus carpenterii*, and the agglutinating foraminiferans were much more abundant on plates positioned higher above the seafloor (Figs 4.2.4, 4.2.5).

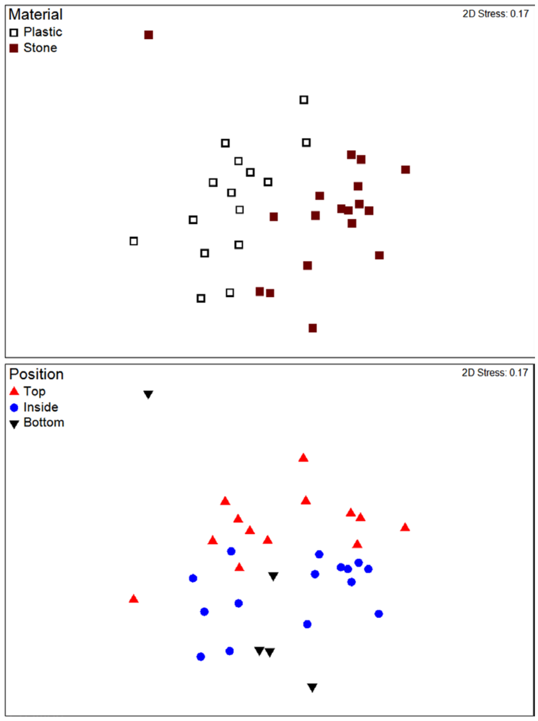

Fig. 4.2.3: Non-metric multidimensional scaling showing community-level differences in recruits on different materials and positions on the settlement lander

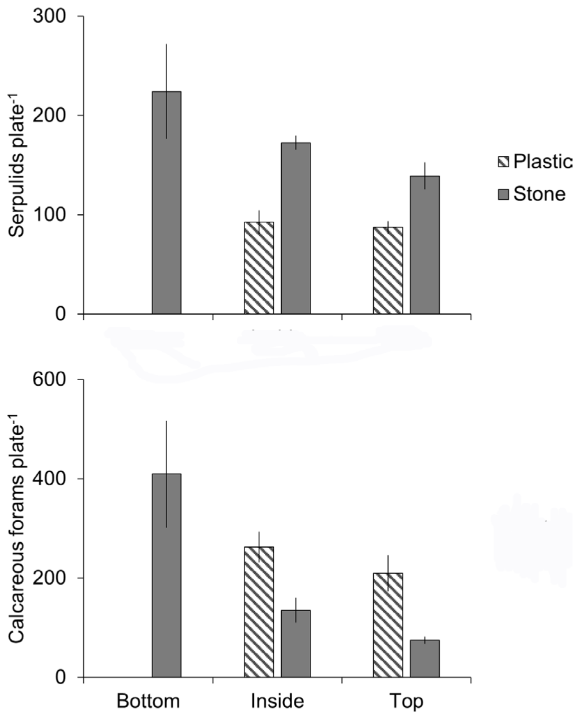

Fig. 4.2.4: Average abundance of serpulids and calcareous foraminiferans on settlement plates, showing a trend of decreasing with increasing height above the seafloor

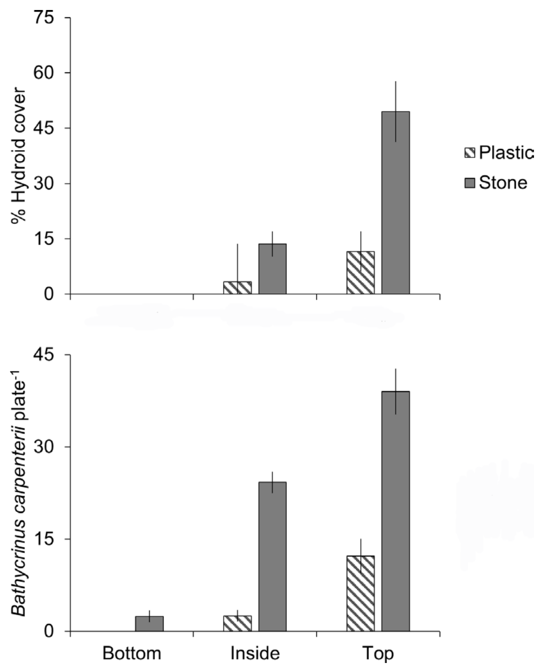

Fig. 4.2.5: Average percent cover of thecate hydroids and abundance of Bathycrinus carpenterii on settlement plates, showing an increasing trend with increasing height above the seafloor

Stone plates may have had more recruitment because they more closely mimic natural substrata. Suspension-feeding species such as the hydroid and *B. carpenterii* were most likely more abundant on higher plates because of the advantage gained in feeding when exposed to faster currents higher up in the benthic boundary layer. It is yet unclear why not all species were more abundant on higher plates, but this pattern may have to do with larval availability (if larvae only disperse very close to the seafloor) or another factor.

The results of the long-term settlement experiment have broader implications for our understanding of colonization in the deep sea, particularly differences between anthropogenic and natural substrata. The abundance of certain invertebrate species, particularly *B. carpenterii*, *C. gelida*, the hydroid, and the serpulid polychaete, were much higher on the settlement plates than on natural habitats in the Fram Strait, which implies that these species may have higher recruitment or be more opportunistic than other invertebrate species, like for example the conspicuously absent *Caulophacus arcticus*. Much remains to be learned about growth of Arctic species, but size measurements of the recruits on the settlement plates will mark a first step in filling this knowledge gap.

4.3 Characterisation of megafaunal communities along environmental gradients

Grant-No. AWI_PS108_00

Objectives

Epibenthic megafauna, often arbitrarily defined as organisms larger than 1.5 cm, play an important role in the deep-sea community. They influence benthic respiration, nutrient cycles and bioturbation, shape community structure through predation and also provide structure at the sediment-water interface. Thus, it is important to understand variations in the megafaunal community with depth, latitude, time and habitat features such as hard substrates (Soltwedel et al., 2009; Schulz et al., 2010; Bergmann et al., 2011; Meyer et al., 2013; 2016; Taylor et al., 2016; 2017). Here, we aim to characterise and compare megafaunal communities from different topographic settings (canyon, depression, open slope).

Work at sea

To investigate the benthic megafauna by a non-destructive method at a large scale and to gain *in-situ* views of the organisms, we used the towed camera system OFOS (Ocean Floor Observation System). Five OFOS transects were conducted at the Molloy Deep, Kongsfjord Canyon, Hayes Deep, and at the northernmost HAUSGARTEN station (N5). Analysis of the OFOS imagery will enable us to assess if megafaunal densities and diversity on the seafloor of depressions (Molloy Deep, Hayes Deep) and canyons (Kongsfjord Canyon) differ from open slope areas (station N5, and OFOS transects by Tekman et al., this issue). The second transect in the Molloy Deep covered a depth range of 2,000 m, which will allow us to assess megafaunal variation in response to local-scale bottom topography.

Despite their large size, certain biota cannot be identified to species level from images alone, e.g. ceriantharians and sponges. To improve the taxonomic resolution of certain yet unidentified megafaunal organisms from the study area, samples were taken by the slurp gun of the ROV KIEL 6000 at the central HAUSGARTEN station (HG-IV).

Preliminary results

Numerical results will only be available once the collected images will have been analysed and species present have been identified. However, a few selected images and photographed species are shown in Fig. 4.3.1. At first impression, the Molloy Deep is characterised by numerous sea cucumbers (*Elpidia heckeri*), small white sea anemones (*Bathyphellia maragaritacea*) and amphipods (*Uristes* sp.). In addition another yet unidentified ball-shaped organism was observed around hard substrates. Many pieces of wood, litter and at least four carcasses were also recorded at this station (Fig. 4.3.1).

The transect at the Kongfjord Canyon appeared to harbour a similar assemblage compared with the shallow station HG-I, which is slightly shallower (1,200 m). Still, some species were seen, which have not been recorded at HG-I (a large anemone, spiky amphipods, a gastropod). In addition, six big holes of unknown origin (pockmarks?) were encountered during the transect (Fig. 4.3.1).

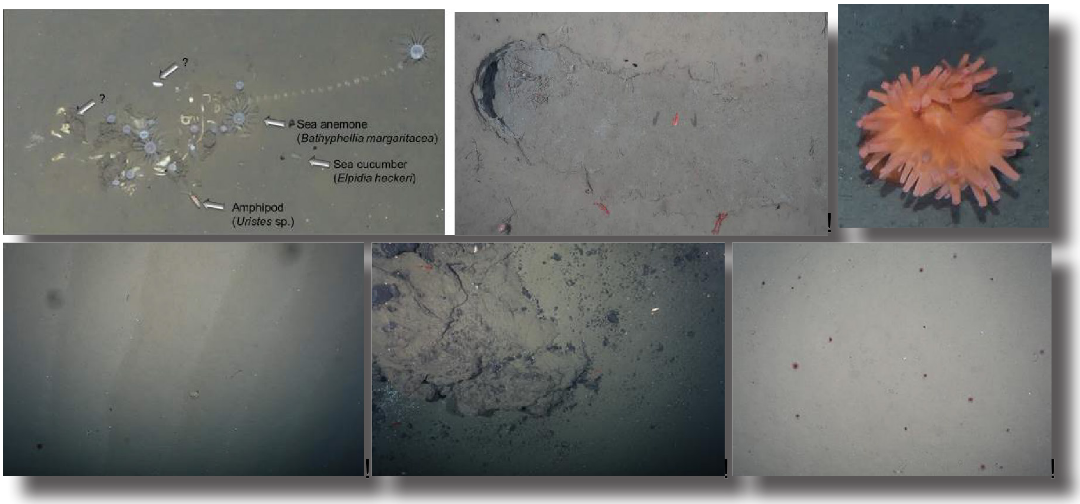

Fig. 4.3.1: Exemplary images taken during OFOS transects (from left to right). Carcass found in the Molloy Deep surrounded by characteristic megafaunal organisms of this station. One of six large holes in sediments caused by yet unknown phenomena. Large anemone recorded during Kongsfjord Canyon transect. Second row: downward directed sand ripples, rocky outcrops and many red cerianthids photographed at the Hayes Deep (Photos: M. Bergmann)

The transect at station N5, which was situated underneath an ice field, harboured a megafaunal assemblage which resembled HAUSGARTEN station N3. The Hayes Deep was home to a megafaunal community, which looked intermediate between the Molloy Deep and HG-IV and showed areas with sediment ripples, which were directed downwards, some rocky outcrops and many purple cerianthids (Fig. 4.3.2).

The specimen collected by the ROV KIEL 6000 will allow the identification to species level by specialised taxonomists of the purple cerianthid and a white sponge (*Phakellia* morphotype) as well as of some other sponges, which often cover dropstones.

Fig. 4.3.2: Sponges, cerianthids and tube worms sampled at central HAUSGARTEN station at 2,500 m water depth by ROV KIEL 6000 for ground-truthing purposes (photos: GEOMAR)

4.4 FRAM pollution observatory: Marine anthropogenic litter in different Arctic ecosystems

Grant-No. AWI_PS108_00

Objectives

Plastic litter contamination of the oceans is a global problem of growing environmental concern (Bergmann et al., 2017). Analyses of camera footage obtained previously at the LTER observatory HAUSGARTEN indicates a significant increase of litter on the seafloor between 2002 and 2014 (Bergmann & Klages, 2012; Tekman et al., 2017). Litter was also recorded floating at the sea surface in the HAUSGARTEN area (Bergmann et al., 2015), and >80 % of the northern fulmars examined from Svalbard have plastic in their stomachs (Trevail et al., 2015). So quite clearly, plastic pollution has found its way to the Arctic.

It has been proposed that litter accumulates particularly in deep canyons and depressions (e.g. Pham et al., 2014). All litter estimates from HAUSGARTEN are currently based on stations from the latitudinal gradient, which represent open-slope environments. Here, we carry out towed camera surveys in different environmental settings to assess the effect of bottom topography on litter quantity. In addition, combination of our data with those from Tekman et al. (this issue) and data from previous years allows large-scale mapping of the distribution of litter. Moreover, we conduct neuston surveys by human observers to determine litter densities at the sea surface. Comparison with data from the seafloor enables us to verify if the seafloor acts as a sink for marine litter.

Recent evidence also suggests high concentrations of microplastics, a degradation product of larger plastic items, in Arctic sea ice (Obbard et al., 2014), sediments (Bergmann et al. in press) and surface water samples (Lusher et al., 2015; Cozar et al., 2017). Here, we determine microplastic concentrations in a water sample taken at the sea surface at the southernmost HAUSGARTEN station to complete the work of Tekman et al. during *Polarstern* expedition PS107. One possible explanation for the high levels of microplastic found in Arctic samples is atmospheric transport. To assess the importance of airborne microplastic contamination snow samples are taken. This work contributes to the *Pollution Observatory* of the HGF infrastructure programme FRAM (Frontiers in Arctic marine Monitoring).

Work at sea

- *Seafloor*

Five OFOS (Ocean Floor Observation System) transects were conducted at the northernmost HAUSGARTEN station N5, the Kongsfjord Canyon, Hayes Deep and twice at the Molloy Deep. Analysis of the OFOS footage will enable us to assess if litter densities on the seafloor of depression (Kongsfjord Canyon, Hayes Deep, Molloy Deep) are higher than at open slope areas (N5).

- *Sea surface*

40 neuston surveys of at least 1 h duration were conducted to determine densities of floating litter and seaweed when the ship was in transit to another station or to Tromsø. This was only possible through the support of four volunteers, who took turns in shifts. Weather and sea state as well as darkness restricted the number of surveys possible.

- *Microplastics*

One sample was taken by a neuston catamaran to determine microplastic concentrations at the sea surface. Snow samples were taken during a helicopter flight to an ice floe to assess airborne pathways of microplastic contamination (Fig. 4.4.1). Sea cucumbers (*Elpidia heckeri*), a starfish (*Bathybiaster vexilifer*) and a sea spider (*Colloscendeis proboscidea*) from the deep seafloor were sampled by the ROV KIEL 6000 to assess contamination of Arctic biota.

Fig. 4.4.1: Images documenting helicopter-based snow-sampling for microplastic on an ice floe (Photos: (1, 2) J. Hagemann, (3) J. Lemburg)

Preliminary results

Several litter items were recorded during each OFOS transect conducted. It consisted primarily of plastic and wood and to a smaller extent also metal and glass (Fig. 4.4.2). However, results with regard to the effect of bottom topography will only be available once the images will have been analysed properly.

Fig. 4.4.2: Exemplary pieces of litter found on the seafloor of the Molloy Deep and Kongsfjord Canyon during OFOS transects (Photos: M. Bergmann)

About 150 litter items were recorded during the 40 sea surface surveys. The distribution of litter appeared to be patchy. Hardly any litter was recorded during surveys in ice fields, where many ice floes were present. Highest litter densities were found in the central area of the Fram Strait but this has to be verified by rigorous geostatistics.

The water sample taken by the neuston catamaran contained at least three pieces of plastic, which were visible by bare eye. However, accurate microplastic concentrations of water and snow samples will only be available after time-consuming extraction and analytical procedures by (µ-) Fourier Transform Infrared Spectroscopy (FTIR).

Data management

Sample processing will mainly be carried out at AWI. Samples from the colonisation experiment will be transported to Woods Hole Oceanographic Institution for further analysis. All OFOS images, videos, metadata and derived data will be uploaded to PANGAEA as will be data on microplastic concentration and results from neuston litter surveys. These data will also be uploaded to the online portal 'LITTERBASE' (www.litterbase.org). Data acquisition from the several types of investigation will be differently time-consuming. The time period from post processing to data provision will vary from one year maximum for sensor data, to several years for organism related datasets. Until then preliminary data will be available to the cruise participants and external users after request to the senior scientist. The finally processed data will be submitted to the PANGAEA data library. The unrestricted availability from PANGAEA will depend on the required time and effort for acquisition of individual datasets and its status of scientific publication.

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5. PHYSICAL AND BIOGEOCHEMICAL PROCESSES AT FRONTS

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Grant-No. AWI_PS108_00

Objectives

The study area, Fram Strait, does not only represent the entrance to the Arctic Ocean, it is also an area of great variability of physical and biogeochemical parameters. The northward flowing Atlantic water is cooled and mixed with cold and fresh polar water. Strong fronts in physical parameters are formed which set the conditions for biogeochemical parameters and the respective biological response. The fronts are no constant features, which exist at the same position for a long time. They are moving features, which disintegrate into smaller filaments meanders and eddys propagating through Fram Strait. As the Coriolis parameter in this region is large, the spatial and temporal scales of the fronts are on the order of kilometres and hours to days. This entails high demands on the observational strategies if these phenomena are to be studied.

- To find such features, satellite and ship based radar data is used. After identifying an interesting area, the ship's thermosalinograph is used to find the front and to determine its exact orientation. Then the front is studied using the underway conductivity, temperature and depth probe (U-CTD), the ship's ADCP, the thermoslinograph, and the Ferry Box. AWI's AUV is deployed to study the upper layers of the water column, which cannot be investigated by *Polarstern,* as the surface layer would be mixed. The AUV carries different sensors to obtain a comprehensive data set of the physical and biogeochemical structure of the water column. A detailed description of the AUV work can be found in section 3.5.

Work at sea

During the cruise we had two opportunities for a ship's survey. As the WaMos System was not running due to a software issue, no Ice Radar data could be used. Satellite data were helpful in finding interesting areas although clouds are always an issue in this region. The fronts where thus found mainly by monitoring the ships thermosalinograph. When a front was found, it was crossed several times to determine its orientation. Then the UCTD was operated from *Polarstern's* portside stern. The probe was operated in free falling mode for 75 – 110 seconds and then immediately pulled back to the surface to start the next cast. The ship was moving with a speed of about 6 kn for most of the transects. At some locations the speed was reduced to 4-5 kn or increased to 10 kn depending on the gradients that should be resolved and the time available.

Two surveys were performed during PS108.

- Survey 1 was conducted on the 26.08. from 17:48 UTC until 3:45 UTC of the 27.08.2017. Six parallel transects of 10 NM length where covered in a distance of 0.5 – 1 NM.

During all of these transects the ship's thermosalinograph and ADCP were monitored. During the third transect, additionally the underway CTD was operated.

- Survey 2 was conducted from 15 UTC on the 02.09. until 3 UTC of the 03.09.2017. Eight transects with a length between 9 NM and 15 NM where covered. During transect 3, 5, and 7 the UCTD was operated. During this survey patches of ice flows were encountered. During these phases the UCTD was lifted out of the water for safety reasons. This introduced larger distances between consecutive UCTD casts.

Preliminary results

During both surveys a strong gradient was observed in temperature (Fig. 5.1, left) and salinity (not shown). The UCTD showed a shallow meltwater layer with about -1°C (Fig. 5.1, right) above warmer and more saline water (not shown).

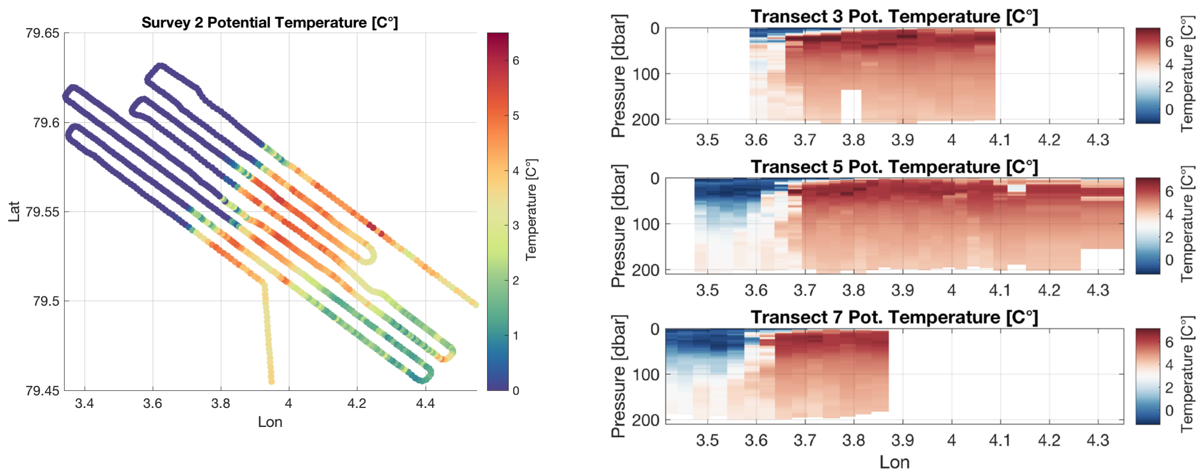

Fig. 5.1: Temperature as observed with the thermosalinograph (left) and from the UCTD (right) during survey 2.

Data management

As soon as data are processed completely they will be uploaded on the PANGAEA database.

6. DEPLOYMENT OF ROV KIEL 6000 DURING EXPEDITION PS108 ONBOARD RV POLARSTERN IN HAUSGARTEN AREA OFF SVALBARD IN THE FRAM STRAIT, NORTHWEST ATLANTIC OCEAN

Fritz Abegg[1], Matthias Bodendorfer[1], Patrick Cuno[1], Hannes Huusmann[1], Torge Matthiessen[1], Arne Meier[1], Martin Pieper[1], Inken Suck[1]

[1]GEOMAR

Grant-No. AWI_PS108_00

Objectives

ROV KIEL 6000 (Figs 6.1 a & b) is a 6,000 m rated deep diving platform manufactured by Schilling Robotics LLC, Davis, USA. It is based on commercially available ROVs, but customized to research demands, e.g. being truly mobile. As a truly versatile system it has been operated from a variety of different national and international research vessels until today (RV *Sonne,* N/O *l'Atalante,* RV *Maria S. Merian,* RV *Meteor,* RV *Celtic Explorer,* RRS *James Cook* and RV *Polarstern*). It is an electrically driven work class ROV of the type QUEST, build No. 7. ROV KIEL 6000 is based at the Helmholtz Centre for Marine Sciences GEOMAR in Kiel, Germany.

Work at sea

Including this cruise, ROV KIEL 6000 has accomplished 260 dives during 21 missions. During PS108, 6 dives could be accomplished (Table 6.1). Further dives were prevented by bad weather. Maximum diving depth was approx. 2,500 m and max. bottom time was 10:23 hours. In total, bottom time accumulated to approximately 35 hours (total dive time approx. 46 hours).

Fig. 6.1: (a) Frontal view of ROV KIEL 6000 (photo: M. Wilde), (b) ROV KIEL 6000 being deployed (photo: C. Nuber)

During PS108, tasks of ROV KIEL 6000 included sediment sampling, using push cores, fauna sampling with slurpgun and ORION manipulator, documentation of the performance of autonomous vehicles (TRAMPER, MANSIO-VIATOR) and the recovery of a long-term settlement experiment

Tab. 6.1: ROV station list PS108

Station Number PS108_	Dive No.	Date [UTC]	Time Start [UTC]	At Bottom [UTC]	Off Bottom [UTC]	Time End [UTC]	Location	Depth [m]	ROV Bottom Time
Test 1	257	22.08.2017	Harbour Test Tromsö, Norway						
004 ROV01	258	25.08.2017	07:22	08:58	15:10	16:51	HG IV	2500	06:12
006 ROV02	259	26.08.2017	08:01	09:04	15:22	16:50	HG IV	2500	06:18
015 ROV03	260	28.08.2017	07:16	07:27	17:50	18:05	GHSM Viator	250	10:23
030 ROV04	261	31.08.2017	15:38	16:39	18:21	19:30	HG IV Recovery	2500	03:52
032 ROV05	262	01.09.2017	09:42	09:58	11:48	12:02	GHSM/ Abandoned	250	02:20
046 ROV06	263	04.-05.09.2017	16:58	17:49	02:49	04:10	Vestnessa Viator	1200	09:00
Total: 6 scientific dives									35:25 h

Tools used during PS108 / handled by the ROV:
- Slurp gun w/ 8 sampling containers (ROV KIEL 6000)w
- Pushcores (ROV KIEL 6000),
- “Senckenberg” Biobox (large) (ROV KIEL 6000)
- Recovery Hook (ROV KIEL 6000)

The sediment sampling configuration included 16 push cores in the portside drawer and 1-2 push core sixpacks in the starboard drawer if needed. Fauna sampling configuration consisted of the Senckenberg Biobox in the portside drawer, the slurpgun and handnets.

Preliminary results

Dive-01

Site:	HAUSGARTEN HG IV		
Start:	N 79° 034.59	E 04°11.90	2400m wd
Objectives:	Tramper	Photo + Video documentation	
	Survey	Photo + Video + Fauna sampling	

During Dive 1 (Figs 6.2 a-c), the AWI Crawler TRAMPER was searched and documented In addition, the so-called slurpgun/suction sampler was used to slurp various invertebrates such as anemones, from the seafloor and either get them in a slurpgun container or transfer them into a bio box.

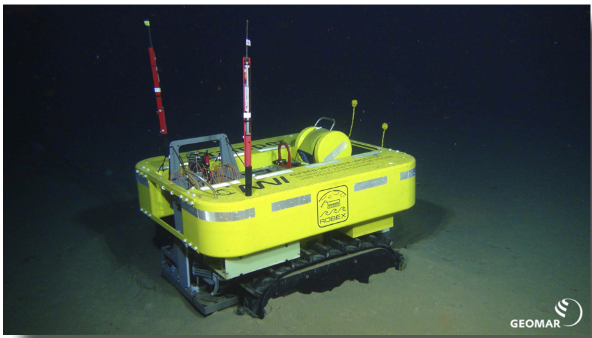

Fig. 6.2a: AWI TRAMPER (Dive 1, 2,500 m

Fig. 6.2b: Dropstone with epifauna (Dive 1, 2,500 m)

Fig. 6.2c: Anemones (Dive1, 2,500 m),

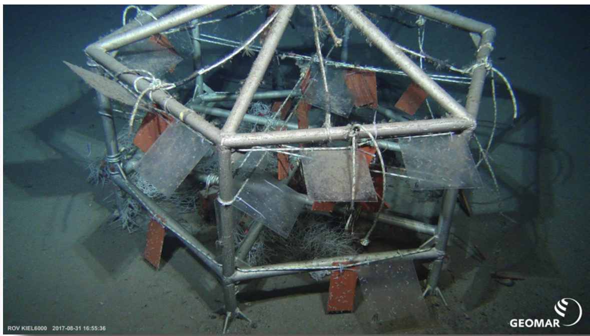

Fig. 6.2d: Settlement experiment just before recovery (Dive 3, 2,500 m)

Fig. 6.2e: Cod at GHSZ (Dive 3, 250 m)

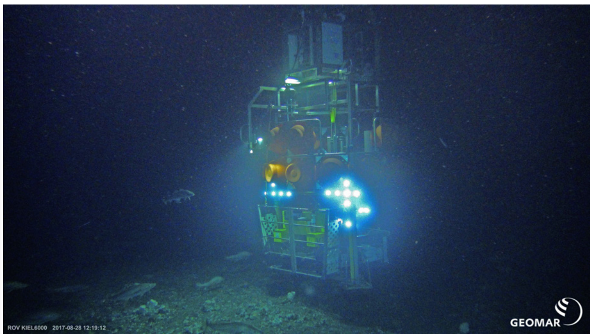

Fig. 6.2f: GEOMAR MANSIO-VIATOR at the seafloor (Dive 3, 250 m)

Dive-02

Site: HAUSGARTEN station HG-IV

Start: N 79° 04.536', E 04°07.571' 2489 m water depth

Objectives: Push coring around artificial drop stones

Photo + Video + Fauna sampling

During Dive 2, sediment samples were taken at artificial drop stones in the AWI-Hausgarten area.

Dive-03

Site: GHSZ, w’ Svalbard, off Prins Karls Forland

Start: N 78°39.38´ / E 9°25.91´ ca. 240 m water depth

Objectives: Video survey of deployment area

Photo + Video documentation of MANSIO-VIATOR deployment

Dive 3 (Figs 6.2 e & f) was conducted to document the deployment of the MANSIO-VIATOR Lander. The Lander was deployed using a second wire, requiring close control of the ROV position and the Lander position. After deployment of the Lander, the second wire was lifted back on deck to minimize the risk of entanglement of the wires.

Dive-04

Site: HAUSGARTEN station HG-IV

Start: N 79° 04.388’, E 04°08.224’ 2432 m water depth

Objectives: Recovery of a metal frame carrying various colonization plates

(approx. 1.5 m in height and diameter; weight: ca. 200 kg)

Photo + Video + Fauna sampling (only if there is spare time)

Dive 4 (Fig. 6.2d) was dedicated to the recovery of a settlement experiment consisting of a steel rig with settlement plates attached. Again a second wire was used to send down a hook. Using two underwater navigation systems the ROV detected the weight attached to the wire holding a hook. The deployment of the weight was visually controlled, to avoid entanglement with the ROV’s umbilical. The ROV grabbed the hook, attached it to the frame which was then lifted by the ships wire, again visually controlled.

Dive-05

Site: GHSZ, w’ Svalbard, off Prins Karls Forland

Start: N 78°39.38´ / E 9°25.91´ ca. 240 m water depth

Objectives: Photo + Video documentation of MANSIO-VIATOR mission

Dive 5, originally dedicated to another MANSIO-VIATOR deployment had to be abandoned due to high swell.

Dive-06

Site: Vestnessa Ridge, w’ Svalbard

Start: 79°0,36´ N / 6°56,19´ E ca. 1200 m water depth

Objectives: Photo + Video documentation of MANSIO-VIATOR mission

Bio sampling

Dive 6 again was dedicated to a MANSIO-VIATOR deployment in a water depth of 1,250 m using the second wire.

For more technical details of the ROV KIEL 6000 please look at:

GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel . (2017). Remotely Operated Vehicle “ROV KIEL, 6000“. Journal of large-scale research facilities, 3, A117. http://dx.doi.org/10.17815/jlsrf-3-160

Data management

All ROV-Data (including telemetry, photos and videos) are archived at GEOMAR on the PROXSYS-system. All metadata are will be submitted to the PANGAEA data library. Copies and extracts of the ROV-data are available on requests at GEOMAR.

APPENDIX

A.1 PARTICIPATING INSTITUTIONS

A.2 CRUISE PARTICIPANTS

A.3 SHIP'S CREW

A.4 STATION LIST

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

	Address
Airbus	Airbus DS Airbus-Allee 1 28199 Bremen Germany
AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar und Meeresforschung Am Handelshafen 12 27570 Bremerhaven Germany
DFKI	DFKI Bremen Robotics Innovation Center Robert-Hooke-Straße 1 D-28359 Bremen Germany
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. Institut für Raumfahrtsysteme Robert-Hooke-Str. 7 28359 Bremen Germany
DWD	Deutscher Wetterdienst Geschäftsbereich Wettervorhersage Seeschifffahrtsberatung Bernhard-Nocht Straße 76 20359 Hamburg Germany
eventfive	eventfive GmbH Auricher Str. 47 28219 Bremen Germany
GEOMAR	GEOMAR Helmholtz-Zentrum für Ozeanforschung Wischhofstr. 1-3 24148 Kiel Germany

	Address
HeliService	HeliService international GmbH Am Luneort 15 27572 Bremerhaven Germany
iSeaMC	iSeaMC GmbH Campus Ring 1 28759 Bremen Germany
Kraken Robotik	Kraken Robotik GmbH Fahrenheitstraße 13 28203 Bremen Germany
Marum/Uni Bremen	Zentrum für Marine Umweltwissenschaften der Universität Bremen Leobener Straße 28359 Bremen Germany
MPI	Max-Planck-Institut für Marine Mikrobiologie Celsiusstraße 1 28359 Bremen Germany
Uni Würzburg	Universität Würzburg Informationstechnik für Luft- und Raumfahrt Sanderring 2 97070 Würzburg Germany
WHOI	Woods Hole Oceanographic Institution 86 Water St. Woods Hole MA 02543-1050 USA

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

Name	Vorname/ First name	Institut/ Institute	Beruf/Profession	Fachrichtung/Discipline
Abegg	Fritz	GEOMAR	Group Leader	ROV-Team
Ahrns	Ingo	Airbus	Engineer	Crawler Viator
Berghäuser	Thorben	GEOMAR	Technician	Crawler Viator
Bergmann	Melanie	AWI	Scientist	Biology; OFOS
Bodendorfer	Matthias	GEOMAR	Engineer	ROV-Team
Busack	Michael	AWI	Engineer	AUV-Team
Cherednichenko	Sergiy	GEOMAR	Engineer	Chemical Sensorik
Cuno	Patrick	GEOMAR	Engineer	ROV-Team
Flögel	Sascha	GEOMAR	Scientist	Geology; Crawler Viator
Gischler	Michael	HeliService	Pilot	
Hagemann	Jonas	AWI	Engineer	AUV-Team
Hasemann	Christiane	AWI	Scientist	Biology; in-situ experiments
Heckmann	Hans	HeliService	Technician	
Heim	Thomas	HeliService	Technician	
Hildebrandt	Marc	DFKI	Engineer	Crawler Viator
Hofbauer	Michael	AWI	Technician	Crawler Tramper
Horvath	Esther		Photographer	
Huusmann	Hannes	GEOMAR	Engineer	ROV-Team
Jager	Harold	HeliService	Pilot	
Kanzog	Corinna	AWI	Scientist	Biology; Lander
Kieser	Jens	DWD	Scientist	Meteorology
Krauß	Florian	AWI	Student apprentice	Sensor technology
Langpap	Bernd	Airbus	Engineer	Glider
Lemburg	Johannes	AWI	Engineer	Crawler Tramper
Matthiessen	Torge	GEOMAR	Technician	ROV-Team
Meckel	Sebastian	Marum	Technician	Glider
Meier	Arne	GEOMAR	Technician	ROV-Team
Meyer	Kirstin	WHOI	Scientist	Biology; in-situ exp.
Nordhausen	Axel	MPI	Technician	Lander
Nuber	Christof	Airbus	Engineer	Crawler Viator
Pfannkuche	Olaf	iSeaMC	Biologist	Crawler Viator
Pieper	Martin	GEOMAR	Engineer	ROV-Team
Rothe	Julian	Uni Würzburg	Engineer	UAV
Ruffer	Michael	Uni Würzburg	Engineer	Glider
Saturov	Dimitar	GEOMAR	Technician	Crawler Viator
Schmidt	Mark	GEOMAR	Scientist	Biogeochemistry / Chemical Sensorik
Schwendner	Jakob	Kraken Robotik	Engineer	Crawler Viator

Name	Vorname/ First name	Institut/ Institute	Beruf/Profession	Fachrichtung/Discipline
Soltwedel	Thomas	AWI	Scientist	Biology; In-Situ experiments
Sommer	Stefan	GEOMAR	Scientist	Biogeochemistry; Chemical Sensorik
Sonnabend	Hartmut	DWD	Technician	Meteorology
Soppa	Bernd	Airbus	Engineer	Glider
Strohmeier	Michael	Uni Würzburg	Engineer	UAV
Suck	Inken	GEOMAR	Scientist	Biology; ROV-Team
Tippenhauer	Sandra	AWI	Scientist	Oceanography; AUV
Utecht	Christine	GEOMAR	Technician	Chemical Sensorik
Waldmann	Christoph	Marum	Scientist	Physics; Glider
Wenzhöfer	Frank	AWI	Chief scientist	Biogeochemistry
Wilde	Detlef	Airbus	Engineer	Crawler Viator
Wilde	Martina	AWI	Scientist	Physics; K&M
Wulff	Thorben	AWI	Engineer	AUV
Zilm	Sandra	eventfive	Filmer	K&M

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

No.	Name	Rank
1.	Schwarze, Stefan	Master
2.	Grundmann, Uwe	Chiefmate
3.	Langhinrichs, Moritz	1st Mate
4.	Hering, Igor	2nd Mate
5.	Neumann, Ralph Peter	2nd Mate
6.	Farysch, Bernd	Chief
7.	Grafe, Jens	2nd Eng.
8.	Haack, Michael Detlef	2nd Eng.
9.	Krinfeld, Oleksandr	2nd Eng
10.	Redmer, Jens	E-Eng.
11.	Christian, Boris	Chief ELO
12.	Ganter, Armin	ELO
13.	Himmel, Frank	ELO
14.	Hüttebräucker, Olaf	ELO
15.	Nasis, Ilias	ELO
16.	Schmidt, Rüdiger	Ships doc
17.	Loidl, Reiner	Bosun
18.	Reise, Lutz	Carpen.
19.	Becker, Holger	MP Rat.
20.	Brück, Sebastian	MP Rat.
21.	Leisner, Bert	MP Rat.
22.	Löscher, Andreas	MP Rat.
23.	Scheel, Sebastian	MP Rat.
24.	Bäcker, Andreas	AB
25.	Hagemann, Manfred	AB
26.	Wende, Uwe	AB
27.	Winkler, Michael	AB
28.	Preußner, Jörg	Storek.
29.	Lamm, Gerd	MP Rat
30.	Rhau, Lars-Peter	MP Rat
31.	Schünemann, Mario	MP Rat
32.	Schwarz, Uwe	MP Rat
33.	Teichert, Uwe	MP Rat
34.	Redmer, Klaus-Peter	Cook
35.	Möller, Wolfgang Hans	Cooksm.
36.	Silinski, Frank	Cooksm.
37.	Czyborra, Bärbel	Chief Stew.
38.	Wöckener, Martina	Nurse
39.	Arendt, René	2nd Stew.
40.	Chen, Dansheng	2nd Stew.
41.	Dibenau, Torsten	2nd Stew.
42.	Duka, Maribel	2nd Stew.
43.	Silinski, Carmen	2nd Stew.
44.	Sun, Yong Sheng	2nd Stew.

A.4 STATIONSLISTE / STATION LIST

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS108_0_Underway-1	2017-08-22	17:00	69.67930	18.99589		WST	profile start	
PS108_0_Underway-1	2017-09-08	15:43	71.80630	19.17937	263	WST	profile end	
PS108_0_Underway-2	2017-08-23	05:59	71.99219	18.90243		ADCP_150	profile start	
PS108_0_Underway-2	2017-09-08	15:43	71.80630	19.17937	263	ADCP_150	profile end	
PS108_0_Underway-3	2017-08-23	06:47	72.13503	18.68763		FBOX	profile start	
PS108_0_Underway-3	2017-09-08	15:43	71.80654	19.17901	263	FBOX	profile end	
PS108_0_Underway-4	2017-08-23	06:47	72.13625	18.68568		PCO2_GO	profile start	
PS108_0_Underway-4	2017-09-08	15:42	71.80725	19.17792	262	PCO2_GO	profile end	
PS108_0_Underway-5	2017-08-23	06:47	72.13690	18.68465		PCO2_SUB	profile start	
PS108_0_Underway-5	2017-09-08	15:42	71.80798	19.17679	263	PCO2_SUB	profile end	
PS108_0_Underway-6	2017-08-23	06:47	72.13768	18.68342		SVP	station start	
PS108_0_Underway-6	2017-09-08	15:42	71.80882	19.17550	263	SVP	station end	
PS108_0_Underway-7	2017-08-23	06:48	72.13881	18.68169		TSG_KEEL	profile start	
PS108_0_Underway-7	2017-09-08	15:41	71.81135	19.17170	264	TSG_KEEL	profile end	
PS108_1-1	2017-08-24	19:43	78.60786	5.06021	2335	LAND	station start	
PS108_1-1	2017-08-24	21:24	78.60777	5.06233	2335	LAND	station end	
PS108_1-2	2017-08-24	22:13	78.61692	5.05609	2338	LAND	station start	
PS108_1-2	2017-08-24	23:22	78.61686	5.06164	2336	LAND	station end	
PS108_2-1	2017-08-24	23:48	78.61864	5.05414	2339	NEMICAT	station start	
PS108_2-1	2017-08-25	00:00	78.60709	5.05363	2339	NEMICAT	profile start	
PS108_2-1	2017-08-25	00:45	78.55371	5.05721	2295	NEMICAT	profile end	
PS108_2-1	2017-08-25	00:50	78.54975	5.05405	2288	NEMICAT	station end	
PS108_3-1	2017-08-25	04:28	79.05992	4.19777	2481	CTDOZE	station start	
PS108_3-1	2017-08-25	05:24	79.05929	4.19405	2486	CTDOZE	at depth	
PS108_3-1	2017-08-25	06:06	79.06015	4.19558	2479	CTDOZE	station end	
PS108_4-1	2017-08-25	07:21	79.05942	4.19218	2485	ROV	station start	
PS108_4-1	2017-08-25	08:59	79.05865	4.19038	2492	ROV	at depth	
PS108_4-1	2017-08-25	16:45	79.05775	4.22210	2485	ROV	station end	
PS108_5-1	2017-08-25	18:25	79.11039	3.24453		OFOS	station start	
PS108_5-1	2017-08-25	19:56	79.10698	3.23067	5389	OFOS	at depth	
PS108_5-1	2017-08-25	20:12	79.10680	3.22821	5389	OFOS	profile start	
PS108_5-1	2017-08-26	00:18	79.07220	3.35108	4811	OFOS	profile end	
PS108_5-1	2017-08-26	02:03	79.07082	3.37855		OFOS	station end	
PS108_6-1	2017-08-26	07:47	79.07565	4.12419	2492	ROV	station start	
PS108_6-1	2017-08-26	09:20	79.07521	4.12336	2494	ROV	at depth	
PS108_6-1	2017-08-26	16:52	79.07837	4.11573	2492	ROV	station end	
PS108_7-1	2017-08-26	17:48	79.07583	4.17550	2441	TSG_KEEL	profile start	
PS108_7-1	2017-08-26	21:24	79.05438	4.16637	2529	TSG_KEEL	profile end	
PS108_7-2	2017-08-26	21:39	79.04687	4.08403	2640	TSG_KEEL	profile start	
PS108_7-2	2017-08-26	23:20	78.94460	4.55633	2641	TSG_KEEL	profile end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS108_7-3	2017-08-26	23:24	78.94593	4.56025	2638	UCTD	station start	
PS108_7-3	2017-08-27	01:04	79.04704	4.02293	2672	UCTD	profile end	
PS108_7-4	2017-08-27	01:20	79.03632	4.01522	2701	TSG_KEEL	profile start	
PS108_7-4	2017-08-27	02:42	78.94002	4.52380	2658	TSG_KEEL	profile end	
PS108_7-5	2017-08-27	02:48	78.93460	4.50518	2679	TSG_KEEL	profile start	
PS108_7-5	2017-08-27	03:45	79.02081	4.04663	2716	TSG_KEEL	profile end	
PS108_8-1	2017-08-27	04:42	79.04319	4.03610	2673	CTDOZE	station start	
PS108_8-1	2017-08-27	04:50	79.04361	4.03408	2674	CTDOZE	at depth	
PS108_8-1	2017-08-27	04:57	79.04415	4.03228	2673	CTDOZE	station end	
PS108_9-1	2017-08-27	06:40	79.04384	4.04336	2667	AUV	station start	
PS108_9-1	2017-08-27	13:24	79.03578	3.93590	2744	AUV	station end	
PS108_10-1	2017-08-27	16:12	79.06043	4.18812	2480	TRAMPER	station end	
PS108_11-1	2017-08-27	14:36	79.05810	4.17762	2503	Glider	station start	
PS108_11-1	2017-08-27	15:07	79.05912	4.17162	2500	Glider	station end	
PS108_12-1	2017-08-27	16:24	79.05513	4.13821	2531	LITTER	profile start	
PS108_12-1	2017-08-27	17:41	79.00633	4.81228	2461	LITTER	profile end	
PS108_13-1	2017-08-27	18:38	78.94771	5.46844	2501	LITTER	profile start	
PS108_13-1	2017-08-27	22:00	78.73817	7.78834	1066	LITTER	profile end	
PS108_14-1	2017-08-28	00:42	78.58522	9.46393	380	UW-MIMS	station start	
PS108_14-1	2017-08-28	01:38	78.58511	9.45975	384	UW-MIMS	at depth	
PS108_14-1	2017-08-28	01:54	78.58490	9.45986	384	UW-MIMS	profile start	
PS108_14-1	2017-08-28	04:13	78.56741	9.47839	392	UW-MIMS	profile end	
PS108_14-1	2017-08-28	04:33	78.56770	9.47813	391	UW-MIMS	station end	
PS108_15-1	2017-08-28	07:10	78.65568	9.43278	248	ROV	station start	
PS108_15-1	2017-08-28	07:27	78.65597	9.43299	249	ROV	at depth	
PS108_15-1	2017-08-28	18:02	78.65704	9.41690	252	ROV	station end	
PS108_16-1	2017-08-28	10:26	78.65601	9.42916	247	MANSIO	station start	
PS108_16-1	2017-08-28	18:42	78.65272	9.43516	244	MANSIO	station end	
PS108_17-1	2017-08-28	19:53	78.58460	9.44969	399	UW-MIMS	station start	
PS108_17-1	2017-08-28	20:24	78.58494	9.45490	394	UW-MIMS	at depth	
PS108_17-1	2017-08-28	20:30	78.58426	9.45695	391	UW-MIMS	profile start	
PS108_17-1	2017-08-29	01:36	78.62320	9.37877	412	UW-MIMS	profile end	
PS108_17-1	2017-08-29	01:54	78.62286	9.37661	414	UW-MIMS	station end	
PS108_18-1	2017-08-29	07:18	78.60625	5.05559	2338	Glider	station start	
PS108_18-1	2017-08-29	09:00	78.60301	4.95335	2365	Glider	station end	
PS108_19-2	2017-08-29	12:00	78.60829	5.01091	2354	LAND	station start	
PS108_19-2	2017-08-29	13:18	78.60792	5.00375	2355	LAND	station end	
PS108_20-1	2017-08-29	18:25	78.76209	4.84111	2361	LITTER	profile start	
PS108_20-1	2017-08-29	19:33	78.97214	4.55561	2585	LITTER	profile end	
PS108_21-1	2017-08-29	20:33	79.16096	4.28623	1947	LITTER	profile start	
PS108_21-1	2017-08-29	21:34	79.27354	4.06705	2499	LITTER	profile end	
PS108_22-1	2017-08-30	04:07	79.94530	3.10538	2566	OFOS	station start	
PS108_22-1	2017-08-30	05:01	79.94758	3.08968	2569	OFOS	at depth	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS108_22-1	2017-08-30	05:06	79.94757	3.08914	2568	OFOS	profile start	
PS108_22-1	2017-08-30	10:15	79.97293	3.00214	2569	OFOS	profile end	
PS108_22-1	2017-08-30	11:19	79.96375	2.98747	2587	OFOS	station end	
PS108_23-1	2017-08-30	11:53	79.97307	2.64630	2690	LITTER	profile start	
PS108_23-1	2017-08-30	13:00	80.02873	1.98934	2865	LITTER	profile end	
PS108_24-1	2017-08-30	13:06	80.03234	1.92752	2733	LITTER	profile start	
PS108_24-1	2017-08-30	14:10	80.08696	1.28089	2877	LITTER	profile end	
PS108_25-1	2017-08-30	20:29	80.07740	0.20320	2812	CTD	station start	
PS108_25-1	2017-08-30	20:37	80.07673	0.20133	2801	CTD	at depth	
PS108_25-1	2017-08-30	20:42	80.07675	0.19919	2797	CTD	station end	
PS108_26-1	2017-08-30	21:34	80.08103	0.21687	2849	AUV	station start	
PS108_26-1	2017-08-31	02:40	80.02058	0.03033	2658	AUV	station end	
PS108_27-1	2017-08-31	06:49	79.70530	0.87326	2689	LITTER	profile start	
PS108_27-1	2017-08-31	07:56	79.59780	1.14066	2960	LITTER	profile end	
PS108_28-1	2017-08-31	08:39	79.55721	1.50722	3066	LITTER	profile start	
PS108_28-1	2017-08-31	09:45	79.47638	2.02569	1989	LITTER	profile end	
PS108_29-1	2017-08-31	09:59	79.45583	2.12259	2101	LITTER	profile start	
PS108_29-1	2017-08-31	12:00	79.29896	3.07045	2697	LITTER	profile end	
PS108_29-2	2017-08-31	12:06	79.29083	3.12159	2955	LITTER	profile start	
PS108_29-2	2017-08-31	13:07	79.18424	3.65703	3442	LITTER	profile end	
PS108_30-1	2017-08-31	15:28	79.07341	4.13832	2485	ROV	station start	
PS108_30-1	2017-08-31	20:52	79.07116	4.14592	2483	ROV	station end	
PS108_31-1	2017-09-01	03:38	78.58489	9.45468	395	UW-MIMS	station start	
PS108_31-1	2017-09-01	04:18	78.58519	9.45462	394	UW-MIMS	at depth	
PS108_31-1	2017-09-01	04:37	78.58544	9.45648	391	UW-MIMS	profile start	
PS108_31-1	2017-09-01	08:23	78.61024	9.42116	394	UW-MIMS	profile end	
PS108_31-1	2017-09-01	08:31	78.61122	9.41967	394	UW-MIMS	station end	
PS108_32-1	2017-09-01	09:43	78.65606	9.43455	248	ROV	station start	
PS108_32-1	2017-09-01	12:10	78.65702	9.43242	249	ROV	station end	
PS108_32-2	2017-09-01	10:09	78.65565	9.43262	249	MANSIO	station start	
PS108_32-2	2017-09-01	12:00	78.65582	9.42840	248	MANSIO	station end	
PS108_33-1	2017-09-01	20:43	78.62472	5.03383	2358	LAND	station start	
PS108_33-1	2017-09-01	22:02	78.63599	5.02613	2352	LAND	station end	
PS108_34-1	2017-09-01	18:16	78.61210	5.04364		LAND	station start	
PS108_34-1	2017-09-01	20:01	78.63059	5.05030	2352	LAND	station end	
PS108_35-1	2017-09-02	02:04	79.34749	5.91751	1774	OFOS	station start	
PS108_35-1	2017-09-02	02:39	79.34525	5.91563	1773	OFOS	at depth	
PS108_35-1	2017-09-02	02:41	79.34523	5.91542	1773	OFOS	profile start	
PS108_35-1	2017-09-02	05:25	79.32641	5.85043	1780	OFOS	profile end	
PS108_35-1	2017-09-02	05:58	79.32837	5.84043	1792	OFOS	station end	
PS108_36-1	2017-09-02	06:33	79.30196	6.15606	1648	LITTER	profile start	
PS108_36-1	2017-09-02	07:35	79.25201	7.00289	1328	LITTER	profile end	
PS108_37-1	2017-09-02	15:06	79.52933	4.16353	3933	CTDTS	station start	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS108_37-1	2017-09-02	15:09	79.53267	4.13957	3987	CTDTS	profile start	
PS108_37-1	2017-09-02	16:20	79.60387	3.64043	3647	CTDTS	profile end	
PS108_37-1	2017-09-02	16:20	79.60423	3.63784	3654	CTDTS	station end	
PS108_38-1	2017-09-02	19:26	79.47695	4.38014	2732	CTDTS	station start	
PS108_38-1	2017-09-02	19:27	79.47740	4.37690	2736	CTDTS	profile start	
PS108_38-1	2017-09-02	19:35	79.48398	4.33141		CTDTS	profile end	
PS108_38-1	2017-09-02	19:56	79.50541	4.18253	3636	CTDTS	profile start	
PS108_38-1	2017-09-02	21:50	79.60695	3.46307	3405	CTDTS	profile end	
PS108_38-1	2017-09-02	21:52	79.60843	3.45247	3447	CTDTS	station end	
PS108_39-1	2017-09-03	00:52	79.46127	4.34087	2657	CTDTS	station start	
PS108_39-1	2017-09-03	00:54	79.46391	4.32195	2678	CTDTS	profile start	
PS108_39-1	2017-09-03	01:41	79.51299	3.97693	3966	CTDTS	profile end	
PS108_39-1	2017-09-03	01:55	79.52813	3.86937	3588	CTDTS	profile start	
PS108_39-1	2017-09-03	03:03	79.59596	3.39097	3267	CTDTS	profile end	
PS108_39-1	2017-09-03	03:04	79.59673	3.38495	3417	CTDTS	station end	
PS108_40-1	2017-09-03	08:48	79.06051	4.16121	2498	TRAMPER	station start	
PS108_40-1	2017-09-03	10:11	79.06000	4.16050	2500	TRAMPER	at depth	
PS108_40-1	2017-09-03	11:00	79.05933	4.15798	2504	TRAMPER	station end	
PS108_41-1	2017-09-03	11:11	79.06197	4.13934	2508	LITTER	profile start	
PS108_41-1	2017-09-03	13:26	79.34626	3.24165	1707	LITTER	profile end	
PS108_42-1	2017-09-03	14:21	79.46655	2.93408	3652	OFOS	station start	
PS108_42-1	2017-09-03	15:31	79.46683	2.93456	3651	OFOS	at depth	
PS108_42-1	2017-09-03	15:43	79.46660	2.93297	3641	OFOS	profile start	
PS108_42-1	2017-09-03	19:56	79.46671	2.75514	3043	OFOS	profile end	
PS108_42-1	2017-09-03	20:44	79.46458	2.73416	3563	OFOS	station end	
PS108_43-1	2017-09-04	07:03	78.56087	10.14504	91	UW-MIMS	station start	
PS108_43-1	2017-09-04	07:25	78.56053	10.14804	91	UW-MIMS	at depth	
PS108_43-1	2017-09-04	07:30	78.56040	10.14711	92	UW-MIMS	profile start	
PS108_43-1	2017-09-04	08:20	78.56418	10.13789	95	UW-MIMS	profile end	
PS108_43-1	2017-09-04	08:58	78.56439	10.13930	94	UW-MIMS	profile start	
PS108_43-1	2017-09-04	09:37	78.56094	10.12454	93	UW-MIMS	profile end	
PS108_43-1	2017-09-04	09:55	78.55968	10.13302	97	UW-MIMS	profile start	
PS108_43-1	2017-09-04	10:21	78.56308	10.14574	90	UW-MIMS	profile end	
PS108_43-1	2017-09-04	10:46	78.56378	10.14924	89	UW-MIMS	profile start	
PS108_43-1	2017-09-04	11:30	78.56241	10.11892	92	UW-MIMS	profile end	
PS108_43-1	2017-09-04	11:50	78.56321	10.11846	93	UW-MIMS	station end	
PS108_44-1	2017-09-04	12:15	78.57660	10.02381	106	LITTER	profile start	
PS108_44-1	2017-09-04	13:27	78.71585	9.01751	489	LITTER	profile end	
PS108_45-1	2017-09-04	14:30	78.83810	8.11058	971	LITTER	profile start	
PS108_45-1	2017-09-04	16:10	79.02979	6.67140	1260	LITTER	profile end	
PS108_46-1	2017-09-04	16:58	79.04709	6.53838	1276	ROV	station start	
PS108_46-1	2017-09-05	04:11	79.04749	6.53541	1276	ROV	station end	
PS108_47-1	2017-09-04	18:13	79.04701	6.53948	1248	MANSIO	station start	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS108_47-1	2017-09-05	05:51	79.04968	6.48224	1291	MANSIO	station end	
PS108_48-1	2017-09-05	06:53	79.04909	6.48016	1293	NOMAD	station start	
PS108_48-1	2017-09-05	14:08	79.05693	6.44868	1285	NOMAD	station end	
PS108_49-1	2017-09-05	08:36	79.04971	6.47767	1292	Glider	station start	
PS108_49-1	2017-09-05	10:05	79.05691	6.39137	1303	Glider	station end	
PS108_50-1	2017-09-05	15:06	79.06652	5.99949	1428	LITTER	profile start	
PS108_50-1	2017-09-05	19:17	79.16937	2.73965	5484	LITTER	profile end	
PS108_51-1	2017-09-05	19:37	79.16560	2.75093	5513	OFOS	station start	
PS108_51-1	2017-09-05	21:19	79.16648	2.74967	5511	OFOS	at depth	
PS108_51-1	2017-09-05	21:27	79.16671	2.74632	5506	OFOS	profile start	
PS108_51-1	2017-09-06	07:03	79.28560	2.39114	3540	OFOS	profile end	
PS108_51-1	2017-09-06	08:09	79.28730	2.38092	3629	OFOS	station end	
PS108_52-1	2017-09-06	15:09	78.98075	3.30697	3950	LITTER	profile start	
PS108_52-1	2017-09-06	17:56	78.54209	4.58627	2380	LITTER	profile end	
PS108_53-1	2017-09-07	15:01	75.81419	11.59536	2099	LITTER	profile start	
PS108_53-1	2017-09-07	18:24	75.25876	12.85894	1825	LITTER	profile end	
PS108_54-1	2017-09-08	08:30	72.87064	17.55473	414	LITTER	profile start	
PS108_54-1	2017-09-08	10:04	72.59535	17.98422	354	LITTER	profile end	

Gear abbreviations	Gear
ADCP_150	ADCP 150kHz
AUV	Autonomous Underwater Vehicle
CTD	CTD aboard RV Polarstern
CTDOZE	CTD AWI-OZE
CTDTS	CTD Towed System
FBOX	FerryBox
Glider	MAPPA
LAND	Lander
LITTER	Litter Survey
MANSIO	MANSIO
NEMICAT	Neuston Microplastics Catamaran
NOMAD	NOMAD
OFOS	Ocean Floor Observation System
PCO2_GO	pCO2 GO
PCO2_SUB	pCO2 Subctech
ROV	Remotely Operated Vehicle
SVP	Sound Velocity Profiler
TRAMPER	TRAMPER
TSG_KEEL	Thermosalinograph Keel
UCTD	Underway CTD
UW-MIMS	Underwater Membrane Inlet MassSpec
WST	Weatherstation

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