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HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

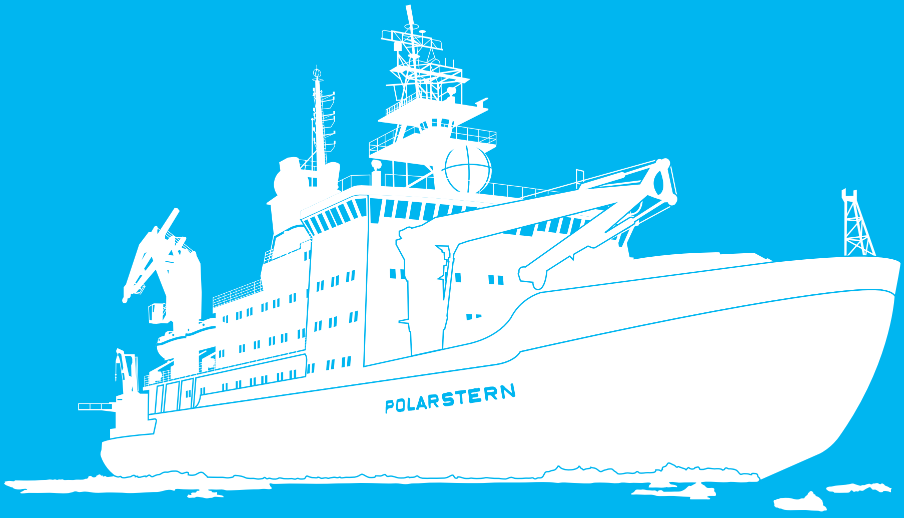
EXPEDITION PROGRAMME PS138

Polarstern

PS138
Tromsø - Bremerhaven
02 August 2023 - 01 Oktober 2023

Coordinator: Ingo Schewe

Chief Scientist: Antje Boetius



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PS138 / ArcWatch-1

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Contents

1. ÜBERBLICK UND EXPEDITIONSVERLAUF

Antje Boetius, Christina Bienhold DE.AWI

Die schnelle Erwärmung der Arktis und der Rückgang des Meereises verändern nicht nur die Hydrographie des Arktischen Ozeans, sondern wirken sich auch in vielfältiger Weise auf biogeochemische und biologische Prozesse aus. Die Expedition PS138 (ArcWatch-1) wird die Biologie, Chemie und Physik des Meereises erkunden sowie die Auswirkungen des Meereis-Rückgangs auf das gesamte Ozeansystem von der Oberfläche bis in die Tiefsee. Hierzu werden die Dynamik des ein- und mehrjährigen Meereises sowie die Rolle der sommerlichen Schmelze und herbstlichen Meereisbildung für die Nährstoffverteilung, Produktivität und Zusammensetzung der pelagischen und benthischen Lebensgemeinschaften wie auch der Export von organischem und inorganischem Material in die Tiefsee untersucht. Im Rahmen der Expedition PS80 (ARK27-3, IceArc) wurden während des bisher größten dokumentierten sommerlichen Meereisminimums in 2012 erhebliche Auswirkungen auf das gesamte Ökosystem des zentralen Arktischen Ozeans festgestellt (Boetius et al. 2013). Elf Jahre später dient die Expedition PS138 einer erneuten Zustandserfassung und vergleichenden Untersuchungen über den Zeitraum einer Dekade. Es werden die gleichen Regionen wie in 2012 wiederbesucht, um mittels interdisziplinärer Prozessstudien die Wechselwirkungen zwischen Eisphysik, Hydrographie, Biogeochemie und Biodiversität des arktischen Systems vom Meereis bis zum Meeresboden zu untersuchen. Dabei werden vergleichende Untersuchungen in den gleichen Arbeitsgebieten wie in 2012 in der Eisrandzone und solchen mit mehrjähriger Eisbedeckung in der zentralen Arktis durchgeführt. Für die Arbeiten werden eine Reihe bewährter und neuer Technologien eingesetzt, wie z.B. Landersysteme und Tiefsee-Crawler. Neben den wissenschaftlichen Einsätzen auf dem Eis und von Bord werden kurz- und langfristige Verankerungen ausgebracht, welche die Physik, Chemie und Biologie des Arktischen Ozeans über verschiedene Zeiträume erfassen. Zudem werden auch Stationen der MOSAiC Expedition wiederholt. Die zu erwartenden Ergebnisse dieser Expedition stellen einen wichtigen Beitrag dar, um die Auswirkung des Rückgangs in der Meereisbeckung auf den Arktischen Ozean und seine Ökosysteme zu quantifizieren.

Die Expedition PS138 (ArcWatch-1) beginnt am 2. August in Tromsø und wird durch norwegische Gewässer in Richtung Norden führen, Spitzbergen östlich passieren und dann entlang der Eisrandzone ostwärts fahren bis auf etwa 130°E. In den Gewässern nordöstlich von Spitzbergen ist eine erste Station mit Einsatz diverser Wasser- und Sedimenprobenahmegeräte geplant, sowie Meeresboden-Beobachtungen mit dem AWI Ocean Floor Observation and Bathymetry System (OFOBS). Im weiteren Verlauf werden ausgewählte Eisstationen angefahren, um eisphysikalische und ozeanographische Messungen durchzuführen, Proben für biogeochemische und biologische Analysen zu nehmen (Eis, Wasser, Meeresboden) sowie benthische Lander einzusetzen. Die Stationsarbeiten werden mit Arbeiten vom Hubschrauber ergänzt. An der ersten Eisstation ist eine Kurzzeitverankerung für die Dauer der Expedition geplant, die auf der Rückfahrt wieder geborgen werden soll. Weitere Verankerungen (2 Parallelverankerungen) sollen im östlichen Teil des Arbeitsgebiets bei etwa 85°N 120°E ausgebracht werden. Die Aufnahme dieser Verankerungen ist während der Expedition ArcWatch-2 in 2024 geplant. Aus dem östlichen Arbeitsgebiet geht es auf nördlicher Route Richtung Nordpol, um auch unter geschlossener Eisdecke ozeanographische, biogeochemische und biologische Untersuchungen durchzuführen. Zum Ende der Fahrt soll die erste Scholle für eine Wiederaufnahme von ausgebrachten Verankerungen auf dem Meereis und weiteren Messungen wiederbesucht werden. Das Schiff kehrt je nach Eissituation entweder östlich oder westlich von Spitzbergen Richtung Bremerhaven zurück. Die Reise endet am 1. Oktober in Bremerhaven. Der genaue Verlauf der Reise ist abhängig von der Eis- und Wettersituation zwischen August und Oktober 2023. Diese Expedition wird unterstützt vom Helmholtz-Forschungsprogramm "Changing Earth – Sustaining our Future" Topic 2, Subtopics 1, 3 und 4 und Topic 6, Subtopics 1, 2 und 3.

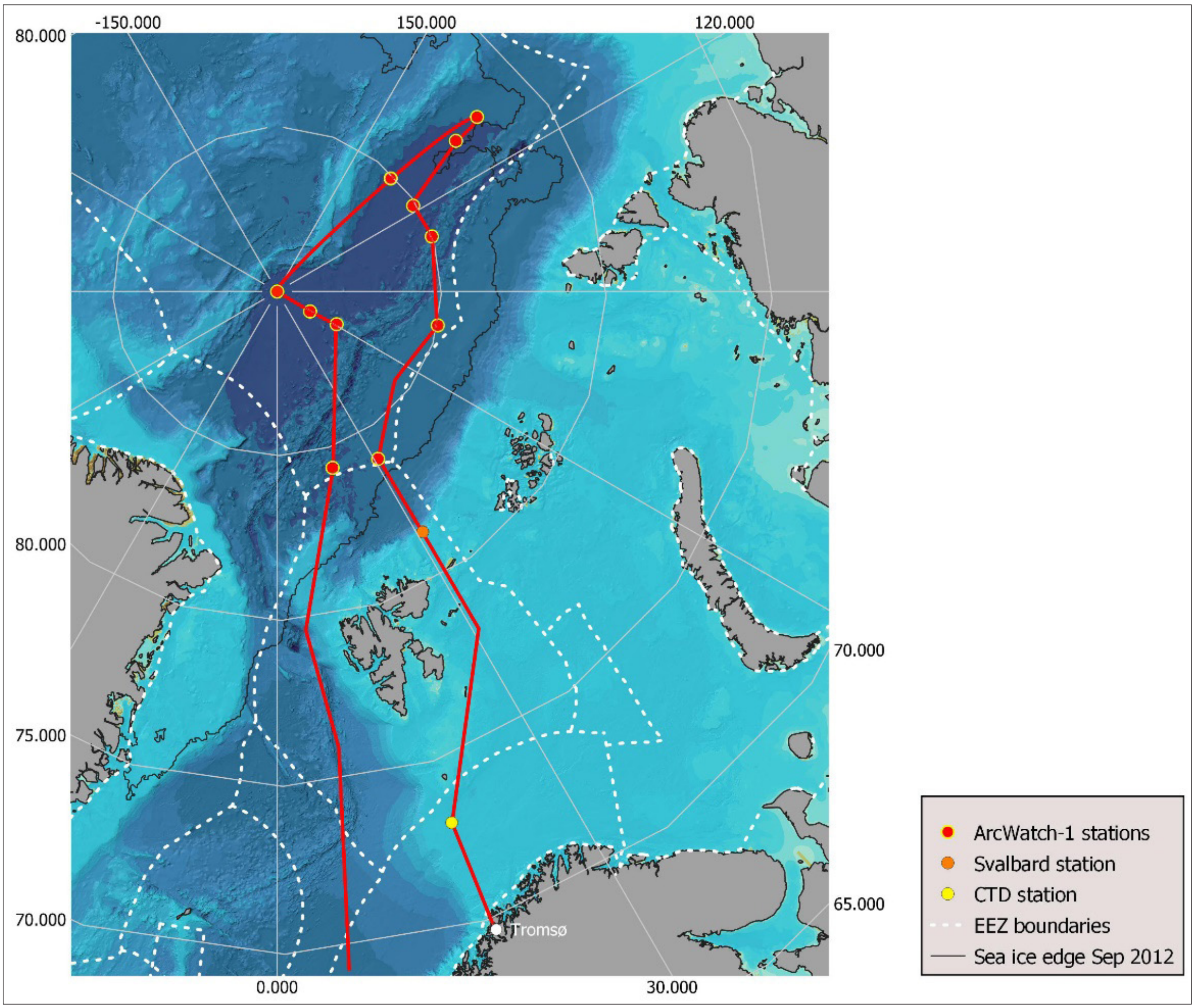

Abb. 1: Geplante Fahrtroute und Stationen der Expedition PS138 (ArcWatch-1). Die Reise beginnt am 2. August 2023 in Tromsø und endet am 1. Oktober 2023 in Bremerhaven. Der genaue Verlauf der Reise ist abhängig von der Eis- und Wettersituation zwischen August und Oktober 2023.

Fig. 1: Planned cruise track and stations of the expedition PS138 (ArcWatch-1). The expedition starts on 2 August 2023 in Tromsø and ends on 1 October 2023 in Bremerhaven. The exact cruise track will depend on ice and weather conditions in August to October 2023.

SUMMARY AND ITINERARY

The rapid warming of the Arctic and sea-ice retreat affects not only the hydrography of the Arctic Ocean, but also biogeochemical and biological processes in various ways. The expedition PS138 (ArcWatch-1) will investigate the biology, chemistry and physics of sea ice, as well as the impact of sea-ice retreat on the entire ocean system from the surface to the deep sea. We will investigate the dynamics of first- and multiyear ice, as well as the role of summerly ice melt and re-growth for the distribution of nutrients, productivity and the composition of pelagic and benthic communities in fall, and the export of particulate matter to the deep sea. During the expedition PS80 (ARK27-3, IceArc) in 2012, which took place during the largest documented sea-ice minimum, substantial impacts on the ecosystem were documented. Eleven years later, the expedition PS138 will evaluate the current ecosystem state and enable comparative studies over the timeframe of one decade. We will re-visit the same regions, and use interdisciplinary process studies to examine interactions between ice physics and biology, hydrography, biogeochemistry and biodiversity of the Arctic ecosystem from the sea ice to the seafloor. This will include comparative studies between working areas in the marginal ice zone and areas covered by multiyear sea ice in the central Arctic Ocean. The work will include the deployment of a range of established and novel technologies, for example moored lander systems and newly developed deep-sea crawlers. In addition to scientific operations on the sea ice and from board, short- and long-term moorings will be deployed to assess the physics, chemistry and biology of the Arctic Ocean across different temporal scales. In addition, we will repeat some studies at former MOSAiC stations. The results expected from this expedition will present an important contribution to quantify the effects of changes in sea-ice cover on the Arctic Ocean and its ecosystems.

The expedition PS138 (ArcWatch-1) will start on 2 August in Tromsø and will lead northward through Norwegian waters. It will pass Spitsbergen on the East and then continue in an easterly direction along the ice margin until around 130°E. A first station is planned to take place north-east of Spitsbergen, where several instruments for water and sediment sampling will be deployed, as well as the AWI Ocean Floor Observation and Bathymetry System (OFOBS) for seafloor observations. In the further course of the expedition, selected ice stations will be visited to perform physico-chemical sea ice and oceanographic measurements, take samples for biogeochemical and biological analyses (sea ice, water, seafloor), and deploy benthic lander systems. Station work will be complemented with helicopter operations. At the first ice station, a short-term mooring will be deployed for the duration of the cruise, and will be recovered on the return path. Further moorings (2 parallel arrays) will be deployed in the eastern part of the working area at around 85°N 120°E. The recovery of these moorings will take place during the expedition ArcWatch-2 in 2024. From the eastern part of the working area, *Polarstern* will head towards the North Pole, in order to conduct sea ice physical, oceanographic, biogeochemical and biological investigations in multiyear sea ice. Towards the end of the expedition a re-visit of the first ice floe is planned to recover moored instruments and buoys from the sea ice. Depending on ice conditions, the ship will pass Spitsbergen in the East or West on its way back to Bremerhaven. The expedition will end in Bremerhaven on 1 October. The exact cruise track will depend on ice and weather conditions between August and October 2023. This expedition is supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 2, Subtopics 1, 3 and 4, and Topic 6, Subtopics 1, 2 and 3.

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2. SEA-ICE PHYSICS

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Objectives

Sea ice is an integrator between the atmosphere and the ocean. Studying the physical properties and key processes of sea ice and its snow cover is the main objective of our work during ArcWatch-1. This work has strong linkages to all other groups, in particular the ecosystem and biogeochemical properties and processes of sea ice. The overarching objectives of the ice physics work during ArcWatch-1 are:

- Better understand the ongoing changes of the sea ice in the central Arctic. This work is embedded into various observational programmes and previous expeditions. In particular, we aim to compare changes in sea-ice conditions with the IceArc expedition (PS80) in 2012 (Boetius et al. 2013)
- Better understand the seasonality of sea ice and snow processes over the course of the year. We aim to quantify processes in the transition from melt to freeze-up conditions. This will closely link to the MOSAiC expedition in 2019/2020 (e.g., Nicolaus et al. 2022)
- Advance our understanding of atmosphere-ice-ocean interaction, in particular with respect to thermodynamic processes and the role of sea ice as a habitat and barrier for atmosphere-ocean interaction
- Advance observational capabilities, by gaining experience and new types of data sets from new instruments and measurement systems
- Calibrate a hybrid sea-ice model (developed in a parallel project) in an optimal experimental design setup on board of *Polarstern*

More specifically, our objectives and work may be sub-divided into four sub-programmes, each of them contributing to an improved understanding of the sea ice, snow and melt-ponds system and its linkages:

Mass balance

Our goal is to study the mass balance and thickness distributions on different spatial and temporal scales. ArcWatch-1 contributes to our Arctic sea-ice thickness monitoring programme performed from vessels and aircraft. During the expedition, we will measure sea ice and snow distribution along the cruise track (across the Arctic) and with higher spatial resolution in the regions of each ice station (floe-size distributions). In addition, instruments will be deployed to cover mass balance parameters over the annual cycle (seasonality).

Energy budgets

The main objective of the optical work during ArcWatch-1 is to quantify the horizontal and vertical distribution of short-wave radiation (hyperspectral and broadband), as it is reflected back to the atmosphere, absorbed in snow, melt ponds and sea ice, or transmitted into the uppermost ocean. These budgets will be obtained on different spatial and temporal scales, ranging from point measurements and local transects to mapping of radiation conditions on floe-scales from above and below. This work continues studies from previous expeditions, in particular IceArc 2012 and MOSAiC 2019/2020. In addition, it will be important to quantify the changes of the sea-ice surface conditions (e.g., deteriorated sea ice, scattering layer) and the internal structure of the sea ice. An additional objective is to provide improved data sets also for satellite-data validation and model improvements.

Another important element connecting the mass and energy-budget studies is the fate of meltwater. The accumulation in melt ponds (surface) and a meltwater layer right under the sea ice is expected to change over time during this season and change towards refreezing rapidly. The objective is to study these melt water budgets and their role in re-freezing of the ice pack.

Bio-physical linkages

The role of sea ice as a habitat needs to be much better understood, while the extreme spatial and temporal variability adds most complexity. In addition to optical mapping of sea ice from above and below, sampling of sea ice, melt ponds and snow is needed to derive its bio-physical properties. This allows creating budgets of biomass as well as improving process understanding and linkages. Mapping optical properties below the ice across different stations will play a central role in this subcomponent. To provide a baseline for *in situ* ROV optical data with sampled biogeochemical variables by other groups, we will also utilize a novel ice-core scanning system harnessing the full range VIS-SWIR and sub-mm resolution to further link vertical biological and chemical and structural properties of the ice. While we will focus on the quantification of the physical environment, this work will strongly be linked to the work of the ecological group (Chapter 4).

Ice floe dynamics and numerical model improvements

It is important to directly connect field observations and numerical models to calibrate a hybrid sea-ice model in an optimal experimental design setup. Due to the nonlinear processes involved in the floe scale dynamics, the required density and precision of measurements to determine the quantities needed for model calibration is not known a priori and needs to be identified in alternating processes of data collection and model calibration. The hybrid model explicitly describes the interactions between sea ice, ocean, and atmosphere at the floe scale using interacting particles (ice floes). To calibrate the hybrid sea-ice model, we need a variety of data describing the nature, dynamics, and interplay of individual ice floes with their environment. In particular, this includes the following:

- Information on the drift of single sea-ice floes
- Characteristics of ice floes such as their size, shape, height
- Environmental data, such as wind velocities

The calibration of these model parameters requires optimisation problems to be considered. We will analyze the sensitivities of a parsimonious model to study the impact of the different parameters and measurements on this calibrated model. This approach allows us to collect exactly and only those data that have a large impact on the model accuracy.

Work at sea

The work at sea can be grouped into different tasks, as listed below by main methodology. Most work will be performed during ice stations when the vessel is drifting along with an ice floe. We plan ice stations for a duration of 8 to 72 hours. Additional observations will be made by helicopter surveys in the vicinity (< 60 nm) of the vessel. Ice conditions and supplemental information will be obtained along the entire cruise track, while sailing through ice-covered waters.

Airborne measurements

We will use airborne electromagnetic induction sounding to measure sea-ice thickness by helicopter surveys. We will fly the newly developed sensor, the AWI EM-Bird, along the entire cruise track, while sailing through the sea ice. This system will reveal sea-ice thickness distribution functions on local scales (< 60 nm) around the vessel. In addition, this work will help to further develop the system and gain more experience in different ice conditions.

We will conduct drone-based (type: DJI Mavic 3) photo surveys of each ice-station floe to map the sea-ice surface conditions with high-resolution visual photographs. These photographs will be stitched afterwards and allow surface descriptions, classifications, and the quantification of surface properties, such as surface albedo.

Surface measurements during ice stations

We will conduct various measurements on the sea ice with the aim to quantify sea ice, snow, and melt-pond properties, as well as their distribution. These measurements are planned to cover all different ice types and features present on the ice station. These measurements include:

- Surface albedo measurements using the ASD hyperspectral radiometer and Kipp/Zonen pyranometer
- Under-ice meltwater/melt pond surveys in coordination with the MOSAiC meltwater-working group measuring vertical profiles of temperature and salinity in the upper 25 m of the ocean
- Spatial surveys of under-ice meltwater consisting of drill transects and thermohaline measurements of the upper 5 m of the ocean
- Surface melt-pond surveys, especially to link meltwater sources, sinks, and pathways
- Repeat measurements of basic surface scattering layer (SSL) properties at a floe which will be revisited to determine SSL evolution during freeze-up
- Sea-ice coring, melt-pond water, and snow sampling for analyzing physical properties, such as temperature, salinity, stratigraphy, density
- Ice-core scanning for biophysical (e.g., Chl-a, porosity and brine channel space) and chemical properties (e.g., gypsum)
- Transect measurements of sea ice (total) thickness with GEM-2 sensors
- Transect measurements of snow depth with MagnaProbe sensors

Remotely operated vehicle (ROV) operations

We will operate the AWI ROV system “Beast” (Katlein et al. 2017) with its interdisciplinary sensor suite. The ROV will be launched through the sea ice during each (> 8 hours long) ice station and can operate in a radius of 300 m around the access hole to access all different ice types present at that station. Main dive missions are:

- Horizontal (2 m depth) and vertical (to 100 m depth) surveys of light conditions under sea ice using radiance and irradiance sensors
- Mapping the microscale under-ice habitat patterns with an Underwater Hyperspectral Imagery (UHI, Ecotone system)
- Mapping of sea-ice draft (thickness) using a multi-beam sensor
- Visual mapping of the sea ice and its associated life from underneath
- Visual inspection and video documentation of installed instrumentation
- Towing plankton nets

Autonomous measurements and station revisit

We will deploy a large suite of autonomous measurement platforms (buoys) during the ice stations and partly by helicopter in the vicinity of the main buoy floes. These systems will then report their data along their drift until they fail. This will extend the observational period of ArcWatch-1 far beyond the expedition time. We aim to build a small distributed network of sensors and stations, as realized during MOSAiC and other expeditions. The main deployment regions for this work will be:

- the first ice station north-east of Svalbard, which will be revisited later during the expedition;
- the station furthest upstream of the transpolar drift;
- the starting positions of the MOSAiC drifts (beginning of Legs 1 and 5);
- the *North Pole station*.
- The instrumentation of most stations will be left to drift with the ice, but we aim to re-visit the first ice station as the last station after approx. 6 weeks again. This will allow also more complex repeat-measurements and collection of the instruments and their data after this short drift.

We plan to deploy the following types of stations, mentioning the main parameters of each system. All stations report their geographic position in addition. Measurement intervals are mostly set to 1 hour. The planned number of units is given in brackets.

- (8) Snow Buoys measuring snow accumulation and basic meteorology
- (8) Sea-ice mass balance buoys (thermistor string buoys, type SIMBA) measuring air, snow, sea-ice and water temperature, thermal conductivity and thus sea-ice thickness
- (4) Seasonal Ice Mass Balance (SIMB3) buoys measuring air, snow, sea-ice and water temperature and sea-ice thickness

- (1) Snow Thickness and Temperature Observation System (SnowTATOS). This is a new autonomous snow monitoring network and an addition to the existing SIMB3 buoy. It allows distributed, remote observation of snow properties, while also providing the standard SIMB3 mass balance observations.
- (1) Autonomous weather station measuring surface meteorology of air temperature, barometric pressure, wind speed and velocity, humidity, solar short- and longwave radiation
- (2) Radiation stations measuring hyperspectral irradiance above (incoming and reflected) and below (incoming) the ice
- (10) Surface velocity profilers (SVP) measuring barometric pressure and partly surface temperature
- (5) Time-lapse cameras taking photographs of the surface conditions, including systems monitoring ablation stakes for surface ablation and accumulation estimates
- Additional systems for oceanographic measurements

Floe dynamics and numerical model work

We will conduct both, data collection and model calibration, on board. During ice stations and additional short stops of the vessel, i.e., the measurement points for oceanographic work in between ice stations, we will conduct measurements with onboard cameras. For validation, we will also analyse the data obtained from at least one helicopter survey (onboard camera+ EM-Bird) and at least one position transponder (AIS system) deployment, giving the floe coordinates and movement. This collected data will be used for the calibration of the hybrid sea-ice model.

To derive the floe characteristics, we will process the data with an extended version of an image processing algorithm. The collection of data directly feeds into an update of the sea-ice model. Aim of this step is to perform the required mathematical modeling and simulation to calibrate the new sea-ice model tuning model parameters such that simulations and observations get into agreement. Given sufficient data of highest accuracy we would immediately obtain the final model.

The process of measurement and model calibration is embedded in a circular optimal experimental design procedure. The goal of this is to selectively collect data so that model accuracy is maximized. A sensitivity analysis will allow us to analyze acquired measurement data and their error propagation. This will then help us to adjust the measurement methodology in subsequent measurement operations so that the accuracy of the resulting model is efficiently increased.

Supplemental observations (on board)

We will operate a panorama camera (type Panomax) above the crow’s nest during the entire expedition, taking regular (e.g., 20 min intervals) photographs of the sea ice and weather conditions.

Sea-ice observations are conducted from the bridge of *Polarstern* while the vessel is moving through ice, describing the conditions within a radius of 1.5 nautical miles around the vessel. The list of parameters that are recorded is comprehensive, and includes for example ice concentration, floe size, fraction of ridged ice, ice thickness. In addition, several parameters describing the weather conditions and large fauna present are also included as part of the procedure.

Preliminary (expected) results

Mass balance

Our mass balance work (airborne, on ice, buoys) will contribute to the long-term record of ice mass balance observations in the central Arctic. We will compare the ArcWatch-1 data to results from previous studies, including the MOSAiC drift and aircraft campaigns (e.g., IceBird). Comparisons will also include work with data from the International Arctic Buoy Programme (IABP). All together this will contribute to the monitoring of the dramatic thinning of sea ice in the central Arctic and along the Transpolar Drift. The data set will allow distinctions of mass balance for different sea-ice regimes, regions and their seasonality.

Deploying the SnowTATOS network and other snow depth sensors will be an opportunity to demonstrate a new technology for observing snow depth and variability on Arctic sea ice. Spatial and temporal variability of snow depth is an important and understudied parameter in the sea-ice system. This deployment will be an important initial demonstration of the system, and we hope it will provide valuable data on snow depth variability, thermal properties, and additional estimates of ice thickness.

Under-ice meltwater surveys will help us understand the spatial distribution and characteristics of these features, which are likely very important for ice mass balance, biogeochemical fluxes, and ecological communities but are very poorly understood.

Energy budgets

The surface albedo surveys will contribute to the long-term record of albedo measurements in the central Arctic. These surveys will directly be merged with the aerial photography from the drone measurements to derive surface albedo maps from the ice floes at different times and in different regions. They will allow to characterize energy budget changes in the transition from melting to freezing conditions.

Radiation mapping from the ROV will provide a better understanding of transmission properties during the melt season and into freeze-up. These measurements will complement the surface observations and allow conclusions on the energy partitioning from the atmosphere into the upper ocean with high spatial resolution. The measurements will enable us to derive a 3-dimensional picture of energy budgets of different snow, melt pond, and sea-ice conditions (melting ice, new ice, ridges, leads, etc.). These observations will help fill observation gaps from the MOSAiC expedition and will help us continue to characterize and understand the variability in the transition from the melt season to the winter.

Bio-physical linkages

The high-resolution UHI data acquired *in situ* across different stations, is expected to be able to track fine and medium scale patterns of sea-ice biophysical properties (biomass, under-ice roughness and topography) that can be related to biogeochemical and ecological processes being monitored by other groups (e.g., grazing, and sloughing and biogeochemistry). Through emerging ice core scanning technologies, we aim to develop Arctic-tailored bio-optical models that permit us to quantify and extrapolate key biological properties when they are applied to the ROV data. In addition, the ice core scanning technique aims to explore and deliver new methods that can capture new biogeochemical interactions in sea ice such as gypsum in slices from ice-cores to see how it is upconcentrated in brine channels.

Ice floe dynamics and numerical model improvements

We expect to obtain sufficient measurement data to calibrate the hybrid particle continuum sea-ice model. In particular, this includes (1) accurate modelling of free drift configurations of individual floes for different scenarios (floe geometry, wind and ocean velocities); and (2) direct interaction of floes to include effects like adhesion, repulsion and change of geometry and topology by physical stress. The upscaling of the calibrated model is the main task following the expedition.

A result on its own is the methodological framework for processing camera data including easy to use computer scripts that perform geometric transformations (e.g., lens distortion, correction of camera angles, correction of ship motion). These tools will be prepared in such a way that they can be used for similar data processing tasks in environmental sciences.

Finally, the sensitivity analysis performed as part of the optimal experimental design loop will help to understand dynamics of ice floes and their interactions.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied. Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

Along with the data we will also publish documented versions of all computer scripts that are required for the evaluation. The hybrid sea-ice model which is developed in a parallel DFG project by C. Mehlmann will be put under an open license and maintained in an open GitLab repository.

This part of the expedition is supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 2, Subtopic 1.

In all publications based on this expedition with co-authorship by any participant listed above, the **Grant No. AWI_PS138_04** or **AWI_PS138_09** (Mehlmann, Richter) or, in case of multidisciplinary work, **AWI_PS138_00** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://doi.org/10.17815/jlsrf-3-163.

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3. PHYSICAL AND CHEMICAL OCEANOGRAPHY

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Grant-No. AWI_PS138_03

Objectives

The central Arctic Ocean is an important part of the global climate system, yet, notoriously under-observed. Decades of repeat surveys using icebreakers and autonomous instrumentation and, to some extent, remote sensing, have allowed identifying variability on interannual to decadal time scales, covering most of the Eurasian and Amerasian basins (e.g. Behrendt et al. 2018). Large-scale changes have been identified by temperature and salinity profile data, e.g. liquid freshwater content (e.g. Rabe et al. 2014). Water sample analysis has led to further insight into water mass pathways by using various tracers (e.g. Bauch et al. 2011) and macronutrients (e.g. Alkire et al. 2017), or into carbon storage (Ulfsbo et al. 2018). *In-situ* sensor data of some of these properties had recently been available and were analysed (e.g. Stedmon et al. 2021). To identify further development of the variability, in particular, in the light of the "new Arctic" (e.g. Weingartner et al. 2022, and references therein) requires repeat hydrographic surveys and deployment of autonomous instrumentation. Further attention has been paid to local process studies on the scale of one ice floe and the surrounding region, e.g. MOSAiC (Rabe et al. 2022; Nicolaus et al. 2022; Shupe et al. 2022) and N-ICE (Granskog et al. 2018). However, further research and *in-situ* observation is needed to shed light on these processes and, ultimately, improve model parameterisation and our understanding of the Arctic and global climate system. The team aims to both improve the temporal and spatial data coverage on the basin scale as well as use the extensive ice stations to study local processes, such as leads, shallow ocean stratification and feedback with the ice, snow and atmosphere, considering the physical and chemical environment and the ecosystem. The study is part of the ArcWatch series of *Polarstern* expeditions and embedded in wider frameworks, such as the International Arctic Buoy Programme (IABP; https://iabp.apl.uw.edu/) and GEOTRACES (e.g. Charette et al. 2020).

Work at sea

As part of the physical oceanography work we will measure various seawater properties from the ship and from the sea ice. In addition, we will deploy autonomous instrumentation to extend these measurements in time and space. The **ship-based Conductivity Temperature Depth** system mounted on a rosette for water sampling **(CTD/rosette)** will be deployed along sections and during individual stations to record water column **profiles of temperature, salinity, oxygen, optical beam transmission, chlorophyll a (chl-a) and Coloured Dissolved Organic Matter (CDOM) fluorescence, photosynthetically active radiation, and nitrate (Nitrate-SUNA)**.

Water samples will continuously be taken and analysed for the correction of temporal drift and pressure effects of the conductivity and oxygen sensors. The ship-based **150 kHz Acoustic Doppler Current Profiler (ADCP)** will be continuously operated to measure the velocity field of the upper ocean. A duplicate **SBE21 thermosalinograph** will also run continuously to record surface temperature and salinity along the cruise track. During transits in open water, an **Underway CTD (UCTD)** system will be used to record additional hydrographic data, in particular, on the Barents Sea shelf. During transits through ice-covered seas, **eXpendable CTDs (XCTD)** will be used to increase the spatial resolution of the regular CTD sections in the upper water column and to extend the CTD measurements horizontally alongside the cruise track from ice floes reachable by helicopter. The latter measurements will also be carried out using a light-weight, **self-recording CTD sensor package** with a **motorised fishing rod**. To aid identifying water masses with respect to ice formation and melt, and continental runoff, we will take samples for **oxygen isotopes (d18O)**, primarily from the CTD/rosette.

During ice stations, a **microstructure profiler (MSS)** will be deployed through a hole in the ice to measure **temperature, salinity, oxygen, chl-a fluorescence**, as well as **shear** to study **turbulent exchange processes**. This will be complemented by **ice-based nitrate (Nitrate-SUNA) profiling** to determine the turbulent exchange of nutrients. A particular focus of our ice work will be to investigate the spatio-temporal variability of the **thin melt water layer beneath the sea ice**. New methods and measurement protocols will be tested, as the ice-ocean boundary is typically difficult to sample. Whenever the conditions allow, we will use a small boat to obtain CTD and MSS profiles in open leads, and to deploy and recover a **floating ADCP**.

Apart from shallow stratification and melt water layers we will focus on the **dynamics** and **fluxes in the ice-ocean boundary layer (IOBL)**. When sea ice is forced to move by winds, the vertical shear of flow between ice and ocean may produce turbulent motions in water, resulting in diapycnal fluxes of momentum, heat and salt. They subsequently affect the heat budget near the ice bottom, and hence the thermodynamic growth and decay. Using an **eddy-covariance system (ECS = Nortek Vector + JFE RINKO-EC)** and a **high-resolving ADCP (Nortek Signature 1000)** we aim to obtain direct observations of the fluxes for each variable. Additionally, **temperature and conductivity** will be continuously measured in the IOBL using autonomous thermistor- and salinity-chains.

We also contribute to the hardware and setup of a network of **autonomous ice-tethered instrument systems (buoys)** in the central Arctic pack ice in collaboration with the sea-ice physics team and contributing to the **IABP**. We will deploy 2 **ITPs**, in collaboration with **WHOI**, and up to 5 **CTD chain buoys** upstream in the Transpolar Drift, complementing a number of meteorological and sea-ice buoys that will be installed on up to 8 individual ice floes. In addition to the central Arctic buoy deployments, **one ice station** will be conducted close to the ice edge near Svalbard early on in the expedition, which will be **revisited** before returning to Bremerhaven. A large **suite of instruments will be temporarily installed** on this floe, and will be recovered during the revisit. The respective oceanographic instrumentation will include ADCPs, an eddy covariance system, and an array of CTD chains to detect mesoscale features in the upper ocean. Additionally, a number of wave buoys will be deployed to investigate wave-ice interaction in this area.

In collaboration with the **BSH**, two **ARGO floats** will be deployed in the Nansen Basin near Svalbard and in the eastern Amundsen Basin to further improve the use of this technology in the (partly) ice-covered Arctic Ocean. In collaboration with the French Service hydrographique et océanographique de la Marine (**SHOM**), 8 MetOcean **SVP** drifters will be deployed on ice floes along the cruise track to obtain barometric pressure measurements in the undersampled central Arctic Ocean, and 3 **TRUSTED buoys** will be deployed in the Barents Sea to obtain ocean surface temperature measurements for the validation of satellite data.

Beyond the physical oceanography work outlined above, the chemical oceanography programme aims to constrain the links between biogeochemical property exchange in Fram Strait and the central Arctic Ocean (CAO) and to investigate temporal changes of **biogeochemical properties in the CAO**. In order to determine the water column structure in terms of biogeochemical properties, we will collect discrete water samples from CTD/rosette casts along defined transects and fixed stations for the measurement of **dissolved nutrients** (nitrate+nitrite, nitrite, phosphate, silicate, ammonium, total nitrogen and total phosphorus) and **dissolved oxygen**. Measurements will be done on board using a Seal Analytical AA-500 continuous segmented flow nutrient analyser and a Ti-Touch Metrohm titration unit set up with the Winkler titration method. Measurements will be carried out following GO-SHIP best practice recommendations as described in Hydes et al. (2010), Becker et al. (2020) and Langdon (2010). As part of a collaboration with researchers from the University of Edinburgh, we will collect samples for the measurement of **stable N and O isotopes** in dissolved nitrate. These data, in conjunction with other environmental data (e.g., nutrients, temperature, salinity) will be used to investigate N-cycling processes determining the availability of N (e.g., Tuerena et al. 2021a,b; Francis et al. 2022; Santos-Garcia et al. 2022). In the central Arctic Ocean these type of measurements are sparse and thus, new measurements will be most useful to fill in gaps in knowledge. We also plan to carry out **SUNA-Nitrate** profiles during ice stations. These data will be combined with micro-structure profiles to compute **nitrate upward fluxes**. Data will also allow us to improve our observations of the finer vertical structure of nutrient fields. Finally, we plan to measure nutrients in **snow samples** in order to test the hypothesis that some nitrogen inorganic species may be derived from atmospheric deposition, which is not well constrained in the Arctic marine environment (this will be done at an exploratory level).

We will also address the role of **Dissolved Organic Matter (DOM)** in the Arctic marine organic carbon cycle. As a follow-up of the efforts carried out during the MOSAiC expedition, we seek to use chemical characterization of DOM to better constrain the quantity of terrestrial dissolved organic carbon (DOC) in the Arctic Ocean that ultimately is exported to the deep Atlantic via Fram Strait. In addition, we will also characterize DOM in sea ice, snow and the melt water surface layer in order to track organic matter that is derived by ice related primary production and transferred into the ocean surface. For both approaches, we aim at improving our knowledge on how the marine DOM pool is affected by climate change, such as sea-ice decline and altered terrestrial run-off via the Arctic shelves. An on-board experiment will be carried out to track the chemical changes that ice derived DOM experiences when it is incubated with the surface water microbial communities. The experiment aims at tracking DOC from sea ice into the ocean and at acquiring kinetics for the microbial turnover.

All samples will be analysed for **Dissolved Organic Carbon (DOC)** and **Total Dissolved Nitrogen (TDN)**. About 400 selected DOM samples will be extracted and chemically characterized using ultrahigh-resolution mass spectrometry, 3D-fluorescence detection, and delta13C as a measure for the terrestrial carbon contribution.

One of the main mechanisms that couples the surface ocean to deeper layers, especially with respect to the carbon cycle, is the **sinking of organic particles**. However, the separation between suspended, non-sinking organic matter, sinking organic matter and matter with active movement is not always possible by direct measurements in the ocean. The elements thorium and polonium, both **natural radionuclides** represented with several isotopes in the natural uranium and thorium decay series, strongly bind to particles. They are produced at a well-known rate, and deviations between the observed (measured) inventory and their expected production can therefore be used to infer integrated carbon export rates. While thorium-234 (**234Th**, half-life 24 days) is a widely used proxy for carbon export, polonium-210 (**210Po**) is analytically more demanding but has the advantage of being more specific for organic carbon and of integrating a longer period due to its longer half-life (138 days). Both isotope systems have been used in the past in studies of the Central Arctic Ocean and beyond (Roca-Martí et al. 2018; Roca-Martí et al. 2016). During PS138, both isotope systems will be monitored, the 238U/234Th disequilibrium and the 210Pb/210Po disequilibrium. Due to the short half-life in particular of 234Th, together with a small expected export, measurement shortly after sampling, i.e. on board, is required. Therefore, a Risoe beta counter is installed on board inside a purpose-built lab container. For 210Po, processing is also planned on board, and an alpha counter (Octete) will be installed in the same lab container. After the cruise, both sample types require a re-counting to determine the background from other isotopes/the parent. Samples will be usually taken down to 400 m, with 4 L for 234Th and 11 L for 210Po. Methods will largely follow (Roca-Martí et al. 2016). A recent comparison has shown that the type of precipitation (iron (Fe) vs. cobalt-ammonium pyrrolidine dithiocarbamate (Co-APDC)) for 210Po has an effect on the efficiency of 210Po recovery, with higher recoveries seen in the Co-APDC method used here.

Two **seafloor-mounted moorings** will be co-deployed in the eastern Amundsen Basin away from any ridges. One is a physical oceanography mooring that is equipped with a solid 25 m long pipe segment at the top to reach a depth as shallow as 10 m. This mooring encompasses a large number of **CTDs** and **temperature loggers**, as well as **2 ADCPs** and a **Sonovault** sound recorder. The second mooring includes two **Remote Access Samplers (RAS)** in collaboration with the microbiology team. One RAS will be deployed at 25 m and another at 254 m (i.e., the core of Atlantic Water) in **mooring CAO2-01**. Each RAS will be equipped with the following sensors; **Nitrate-SUNA, pH, pCO2 and CTD-O2**, with a additional **PAR** and **EcoTriplet** sensors at 25 m. The RAS will be programmed to collect seawater samples at weekly intervals for the measurement of dissolved nutrients in seawater and for genetic analyses. The mooring further includes **two sediment traps**, an Acoustic Zooplankton Fish Profiler, another Sonovault, an ADCP and a number of CTDs and current meters. The moorings are planned to be recovered in 2024.

Preliminary (expected) results

We expect to have *in situ* sensor data, accompanied by tracer and other chemical measurements, processed a few months after the expedition to elucidate stratification and vertical fluxes associated with leads, sea-ice melt and formation, and surface momentum flux. Further, we will get a first insight into the large-scale state of the Eurasian Basin about 8 years after the previous summer *Polarstern* expedition (PS94) to the same study region, and 3 years after MOSAiC. Some of the tracer data may be processed later than the sensor data, depending on laboratory time being available on land. All going well with instrumentation on board, nutrient data from samples collected during the expedition should be ready by the end of the expedition. Data from sensors and from RAS samples will be available approximately 6 months after mooring recovery in 2024. Overall, we will continue the central Arctic long-term observations and time series of fresh water and other inventory quantities.

Data management

Environmental data will be archived, published and disseminated according to the FAIR principles by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition. By default, the CC-BY license will be applied.

The iridium buoy data will be stored on the server infrastructure of the respective manufacturer, and in the database of the International Arctic Buoy Programme. Selected buoys also report their data directly to the WMO’s Global Telecommunication System (GTS) in near-real time, thereby contributing to improved global numerical weather predictions.

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In all publications based on this expedition with co-authorship by any participant listed above, the **Grant No. AWI_PS138_03** or, in case of multidisciplinary work, **AWI_PS138_00** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://doi.org/10.17815/jlsrf-3-163.

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4. BIOLOGICAL OCEANOGRAPHY AND SEA-ICE BIOLOGY

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Outline

Due to the rapidly advancing climate warming, the Arctic Ocean is experiencing unprecedented changes. The decline in ice coverage by ~13 % per decade compared to the mean September extent for 1981–2010 (Serreze and Meier 2019), coupled with increasing temperatures and declining ice thickness and multiyear ice (Kwok 2018), is already altering the composition of primary producers in the Arctic Ocean (Wassmann and Reigstadt 2011). This could have significant consequences for the food web, pelagic-benthic coupling, and biogeochemical cycling in the Arctic Ocean (Wiedmann et al. 2020). However, the complexity of factors driving Arctic productivity, food webs and other forms of biological interactions regionally, as well as the difficult access to the Arctic, make it challenging to predict future ecosystem dynamics and carbon fluxes for the entire Central Arctic Ocean. During ArcWatch-1, we will study how different ice- and nutrient-regimes impact productivity, community composition, trophic interactions, remineralization, and carbon sequestration and compare this to results from the 2012 sea-ice minimum.

Objectives

The Arctic sea-ice cover is a critical component of the Earth's climate system where it directly reflects sunlight back into space, hosts a unique diversity of life, and plays a crucial role in regulating heat exchange and ocean circulation. The recent record-lows in sea-ice extent in 2012 and 2020 with less than 4 million km^2 of ice cover is accompanied by a shift from thicker multi-year ice to thinner first-year ice in the central Arctic. Shifts from multi-year to first-year ice have large implications for the cryo-benthic and cryo-pelagic coupling, ultimately affecting the entire Arctic Ocean ecosystem. While a reduction in sea-ice thickness may result in a higher primary production of sea-ice algae, it may impact sea-ice associated metazoans which rely on multi-year ice for their development stages. We will identify and study different ice-regimes during ArcWatch-1. These ice-regimes will include marginal ice-zones, ice-covered regions, and leads in sea ice. Both phyto- and zooplankton communities will be collected using nets and we will determine plankton community compositions for the different regions. Rates for primary production and remineralization will be linked to estimates of trophic transfer and carbon export both via passively settling aggregates and actively migrating zooplankton.

Since 1998, remote sensing of ocean colour in the Arctic shelf seas indicates a 57 % increase in net primary production (Lewis et al. 2020), likely enhancing carbon and nutrient fluxes. The transformation from thick multiyear to thin first-year sea ice increases light transmission through the ice (Leu et al. 2015), leading to an increased spatial and temporal extent of sea-ice algae and under-ice pelagic phytoplankton blooms. Such blooms, mainly composed of diatoms, can provide substantial pulses of carbon and nutrients to benthic ecosystems when the sea ice melts (Boetius et al. 2013). As the ice-edge retreats earlier and stronger, it is unclear how it will affect vertical carbon export in the Arctic shelf seas and margins and lateral export from them into the Arctic basins, considering various factors such as the timing of stratification, phytoplankton composition, and carbon export efficiency. However, primary production models suggest that the impact of ice-algae and under-ice phytoplankton blooms on productivity is likely to increase, with ecological consequences for pelagic and benthic ecosystems (Perette et al. 2011). By linking our work to the benthic measurements done during the cruise (Chapter 5), we will be able to directly study cryo-benthic processes and understand how cryo-pelagic mechanisms either enhance or reduce the connectivity between sea ice and benthic communities in the central Arctic.

It is widely recognized that sinking particles serve as a crucial means of transporting carbon and nutrients to heterotrophic organisms in the deep ocean. The microbial loop in the surface ocean plays a crucial role in retaining most of the carbon and nutrients, along with other factors such as particle size and grazer activity, that can significantly affect carbon export efficiency (Henson et al. 2019). Given the ongoing changes in the Arctic Ocean, it is crucial to understand how altering sea-ice regimes and changes in primary producer composition and rates will impact carbon export and interactions between trophic levels through the water column. We will use both moored, ice-anchored, and freely drifting sediment traps in combination with *in-situ* camera systems to study export mechanisms of settling aggregates. Further, combinations of plankton nets and hydroacoustics will allow us to study the role of zooplankton for active carbon export via their vertical migration patterns, both on short and long time-scales. We are especially interested in understanding the role of the meltwater-layer directly below the sea ice for carbon flux attenuation and recycling of nutrients.

Heterotrophic bacteria, linked to the dynamics of phytoplankton blooms, sea ice derived organic matter and sinking particles, are another important component of the biological carbon pump. However, there is still only limited understanding on microbial diversity, distribution and activity across ecosystem compartments in the central Arctic Ocean. Here, we will characterize microbial diversity, functional ecology and connectivity between the sea ice and water column, both spatially and temporally. Through molecular metabarcoding and meta-omics on sea ice and pelagic microbiomes, we will (i) establish an inventory of bacterial, archaeal and microeukaryotic diversity in distinct environmental regimes; (ii) characterize genetic capacities that drive microbial metabolism and carbon cycling; and (iii) provide an overarching perspective on cryo-pelagic-benthic coupling by contextualizing microbial dynamics and interactions with biogeochemical fluxes. This will include specific assays for bacterial chemotaxis (Lambert et al. 2017) using exudates from Arctic ice-algae as chemoattractants, allowing to identify and isolate major players in bacteria-algae interactions. Finally, an important aspect is the largely unknown seasonality in the central Arctic Ocean. To this end, we will deploy autonomous sampling devices on seafloor moorings to generate a complete annual cycle of microbial diversity and functionality. In comparison to long-term datasets from Fram Strait, this will elucidate the extent of seasonality on a pan-Arctic scale, and indicate possible imprints of climate change on temporal dynamics.

Our research will be addressing the following hypotheses:

- Declining silicic acid availability in the marginal ice-zone will decrease primary production.
- Low silicic acid and high nitrate availability will cause a shift from diatoms to non-silicified phytoplankton and ice-algae.

- A shift to non-silicified microalgae will increase zooplankton grazing and generate a stronger trophic link.
- Zooplankton metabolic activity decreases with increasing depth, thereby decreasing conversion of lipid to carbon dioxide at depth during diapause.
- The meltwater-layer below sea ice retains settling aggregates allowing efficient grazing on the aggregates by zooplankton, and the establishment of specific heterotrophic microbiomes.
- Carbon export is high at marginal ice-zones where cryo-minerals are effiently released as sea-ice melts.
- Microbial diversity and functional ecology show distinct signatures relating to sea-ice cover, showcasing adaptations to central Arctic habitats.
- Bacterial chemotaxis is enriched in sea-ice associated habitats, foremost meltponds, in comparison to pelagic seawater.
- Seasonality in the central Arctic Ocean is weaker in relation to boundary regions like Fram Strait.

Work at sea

Pelagic biogeochemical and biological parameters will be sampled using the CTD-rosette sampler to collect water from different layers in the upper 200 m of the water column. Additional samples will be collected from the meltwater-layer directly below the sea ice and as ice-core samples. At selected open ocean stations, we will sample through the entire water column. The sample analyses will include phytoplankton species abundances using microscopy, imaging flow cytometer and molecular biological analysis, chlorophyll a and phaeopigments, HPLC pigments, particulate organic carbon and nitrogen (POC/PON), carbonate, and biogenic silica (bPSi). For pigment and biogeochemical analyses, water will be filtered and stored deep frozen for later analyses in the home laboratory, or samples will be fixed and stored cool until enumeration for species composition.

We will sample *in situ* formed aggregates using a marine snow catcher, freely drifting sediment traps, ice-anchored sediment traps, and moored deep sea sediment traps. We will additionally deploy *in situ* camera systems to measure vertical size-distribution and abundance of aggregates, as well as *in situ* settling velocities of different types and sizes of settling aggregates. We will deploy two long-term moored sediment traps in combination with other sensors and sampling devices (see Chapter 3). A third mooring will be deployed north of Svalbard for the duration of the cruise (see Chapter 5). This mooring will specifically address vertical connectivity to follow pelagic-benthic coupling at high resolution during a relatively short time-scale (~2 months). We will perform direct on-board rate measurements of microbial respiration and size-specific settling velocities on single *in situ* collected aggregates during the cruise. Furthermore, the aggregate composition and type will be determined before aggregates are frozen individually for later determination of biogeochemical composition.

Zooplankton biodiversity and biogeography will be determined using multinets. The net samples will immediately be preserved for later determination of mesozooplankton composition, biomass, size structure and depth distribution using the lab-based ZooScan system. Standard multinet sampling depths are 1,500 – 1,000 – 500 – 200 – 50 m, and, thus, these nets integrate over several hundred meters. To determine the fine scale vertical distribution of meso- and macrozooplankton we will use *in situ* camera systems; ROSINA, UVP, and JellyCam. Zooplankton samples will be used for lipid composition to determine the role of mesozooplankton for the lipid pump in the central Arctic Ocean. Trophic interactions will be identified via natural stable isotope and biomarker analyses.

Microbial diversity will be studied using samples derived from the CTD rosette and sea-ice corers. Water and melted ice will be filtered and frozen until analysis ín the home lab. Furthermore, *in-situ* pumps will sample large volumes of water and microbes allowing for subsequent metatranscriptomic studies of gene expression. Bacterial chemotaxis will be tested by deploying “ISCA” devices in meltponds, as well as setting up ISCA microcosms with seawater and under-ice microbiomes in the ship’s lab. Deploying Remote Access Samplers (RAS) on a seafloor mooring will provide an annual record of microbial diversity and functionality after RAS have been recovered in 2024.

Preliminary (expected) results

We expect to observe a strong impact of ice-regimes on the pelagic and ice-associated plankton communities, which will directly influence the efficiency and magnitude of carbon export to the deeper water depths. Furthermore, release of cryominerals will ballast organic aggregates and potentially enable them to cross the salinity gradients at the base of the meltwater layer. This will result in sporadic export events, where a large fraction of the organic matter that was retained in the meltwater layer is exported to the deep sea and seafloor. We expect this mechanism to be a driving factor for the biological carbon pump in the central Arctic Ocean. During periods with little to low ballasting from cryo-minerals, we expect the meltwater-layer to be a region of high biological activity and efficient grazing on organic aggregates. The aggregates are porous and will be retained at the salinity gradient, allowing extended time for microbial degradation and zooplankton grazing on the aggregates. This means that strongly stratified regions below Arctic sea ice are characterized by retention and only little export takes place without ballasting from cryo-minerals or production of compact and dense zooplankton fecal pellets. These points will directly translate to patterns among microbial communities, which are expected to show distinct taxonomic and metabolic signatures during high-ice conditions. Furthermore, we expect an enriched potential for microbial chemotaxis and carbon cycling in ephemeral, productive habitats like meltponds.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied.

Molecular data (DNA and RNA data) will be archived, published and disseminated within one of the repositories of the International Nucleotide Sequence Data Collaboration (INSDC, www.insdc.org) comprising of EMBL-EBI/ENA, GenBank and DDBJ).

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

This part of the expedition is supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 6, Subtopics 1, 2 and 3.

In all publications based on this expedition, the **Grant No. AWI_PS138_02** or, in case of multidisciplinary work, **AWI_PS138_00** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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5. BATHYMETRY, BENTHIC BIOLOGY AND BIOGEOCHEMISTRY

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Grant-No. AWI_PS138_01

Outline

Due to the difficult accessability of the ice-covered Arctic basins, very little is known about its diversity, distribution and function of benthic communities. One of the central questions about the consequences of the shrinking sea-ice cover is to what extent primary production and subsequent export of organic matter to the seafloor will be affected, and how this will influence the structure and functioning of benthic communities in the Arctic. During PS138 we will assess the diversity of benthic communities across all size classes, i.e. megafauna, macrofauna, meiofauna, and microbes and evaluate it in view of cryo-pelagic-benthic coupling. A key task of this study is the comparison with the benthic biodiversity and foodweb at the same stations in 2012.

Arctic benthic deep-sea communities depend on the sedimentation of particulate organic matter from the sea ice and the water column, which is in turn determined by temporal and spatial variations in sea-ice cover, hydrography, and surface production. Most of the sinking organic matter is recycled in the water column, and the fraction that ultimately reaches the seafloor is either remineralized or retained in the sediment record. The part that escapes remineralization is a key to the long-term storage of carbon in the oceans, facilitated by the biological carbon pump. Benthic oxygen fluxes help to provide a reliable and integrated measurement of the metabolic activity of surface sediments. They quantify benthic carbon mineralization rates and can thus be used to evaluate the efficiency of the biological pump. By measuring benthic oxygen fluxes *in situ* at high spatial resolution, we will assess the carbon mineralization efficiency of deep-sea sediments in the central Arctic.

Objectives

Major objectives of our work include:

- High-resolution seafloor observations and the assessment of biodiversity and distribution of benthic megafauna, and epi- and suprabenthic macrofauna communities in the high Arctic
- Comparison of mega- and macrofauna foodweb structure and relation to sea-ice algal deposits

- Quantitative spatial and temporal comparisons of benthic macrofauna, as well as species descriptions based on morphological and genetic methods
- Assessment of temporal changes in the diversity and distribution of meiofauna and microbial communities at the Arctic deep-sea floor, as well as their functions in regions of varying sea-ice cover
- The characterization of the quantity and quality of deposited organic material and comparison to the past decades with stronger ice cover
- The quantification of pelagic export and benthic remineralization of organic carbon to assess links between surface production, benthic activity and burial of carbon.

Work at sea

Work at sea will include 1) video surveys of food falls, megabenthic communities and bathymetric mapping of the deep-sea floor using the Ocean Floor Observation and Bathymetry System (OFOBS), 2) sampling of macrofauna using a giant box corer (GKG) and an epibenthic sledge (EBS), 3) sampling of surface sediments for meiofauna, microbial communities and biogeochemical measurements using a TV-guided multiple corer (TV-MUC), and 4) the *in situ* assessment of benthic mineralization rates using moored lander and lander-crawler systems.

Megabenthic ecology and high-resolution seafloor topography

The Ocean Floor Observation and Bathymetry System (OFOBS) (Purser et al. 2019, Rybakova et al. 2019) will be deployed at all sites of interest to assess the seafloor megabenthic communities using the integrated 26 megapixel still image camera (iSiTEC, CANON EOS 5D Mark III) and HD video camera (iSiTEC, Sony FCB-H11). OFOBS is additionally equipped with a multibeam system for high-resolution topographic mapping of seafloor structures and, in the case of large sessile fauna, faunal distributions (Purser et al. 2019). The sidescan bathymetry sonar is an interferometric EdgeTech 2205 AUV/ROV MPES (multiphase echosounder) with two sidescan frequencies. An additional compact CTD provides data on the chemical-physical composition of bottom waters during the dive.

The OFOBS is also equipped with a small ROV, which can be released at any time to conduct filming and small manipulations within 50 m of OFOBS, at any depth. This device will be used opportunistically during OFOBS dives, and can also be offered for the recovery of equipment that had failed to be correctly released from the seafloor.

During the expedition, rough 2D photomosaics will be generated using the “Agisoft Metashape” software application. These maps will be provided to onboard cruise participants to aid in determining the appropriate locations for benthic equipment deployment.

Sidescan data will be processed using the “Sonarwiz 7” software application, again to determine suitable sites for subsequent benthic studies.

Following the expedition the raw image and sidescan data will be delivered to the AWI bathymetry team for integration into Arctic mapping products.

Macrofauna

The giant box corer (GBC) will be used to retrieve sediment samples for benthic macrofauna analyses. The instrument has dimensions of 0.5 m x 0.5 m representing a sampling area of 0.25 m^2. On deck, the sediment will be sieved with 0.5 mm mesh size. Half of the subsamples will be fixed in 96 % ethanol and the other half in 4 % formaline for later analyses in the home laboratory.

The EBS (Brandt et al. 2007; Kaiser et al. 2008; Malyutina and Brandt 2012) will be towed over the seabed with the stirred-up sediments being washed through the fine nets to catch the animals in the cod ends. It is equipped with both, a supra- and an epibenthic net (500 µm) on top of each other, with each net leading into a cod end of 300 µm. To prevent the collection of pelagic fauna while ascending or descending, the EBS carries a mechanical opening-closing device. On deck, the cod ends will be partially live sorted, and selected specimens will be hand-picked for genomic and food-web analyses. Large and well-preserved animals will be photographed alive to document the colour patterns. The remaining samples from the cod ends and nets will be immediately fixed for future molecular studies. Sorting of the samples to the higher taxonomic level will begin on board after 48 hours using stereomicroscopes. The samples will be kept cool at all times to maintain their integrity.

Meiofauna, microbial communities and biogeochemical parameters

A TV-guided multiple corer (TV-MUC) will be used to retrieve undisturbed sediment cores at each station. On board, the sediment cores will be observed for surface artifacts and documented visually. Cores will be cut into three sections (0-1 cm, 1-5 cm, 5-10 cm) using a steel plate. Three replicate cores will be sampled for microbiology and biogeochemistry. 1-2 whole cores will be dedicated to porewater extraction and analysis.

Sediment samples will be analysed or fixed for a range of biological and biogeochemical analyses. Biogeochemical analyses of samples on board will include the determination of chlorophyll pigment content as a proxy of organic matter availability, and assays of a range of potential extracellular enzymatic activities. Sediment samples will be fixed for microbial DNA/RNA extraction, microbial cell counts, phospholipid analyses, porosity, and the measurement of total organic carbon. These analyses will all be performed in the home laboratories. In addition, pore water will be extracted and fixed for the analysis of nutrients, DIC (dissolved inorganic carbon), alkalinity, and iron in the home laboratory.

3-6 cores will be sampled and fixed for morphological (4 % buffered formalin) and molecular (95 % ethanol) analyses of meiofauna. If possible, selected meiofaunal organisms from the GBC will be used for barcoding to build a reference library, which will enhance the output of the metabarcoding analyses. Sample processing, identification and further analyses will be conducted in the home laboratories.

Wherever possible, an additional core will be dedicated to the sampling for later microplastics analyses (collaboration Melanie Bergmann, AWI).

In situ benthic fluxes

In situ measurements will be performed using three moored Lander-systems, designed to be operated under permanent sea-ice cover, to study benthic oxygen uptake at the sediment-water interface (Wenzhöfer & Glud 2002; Boetius et al. 2013), as well as a new lander-crawler system. The Landers are equipped with two 2-axis profiler-systems – one electrochemical microprofiler with microelectrodes and one fiberoptical microprofiler with optodes. The 2-axis electrochemical microprofiler will be used to perform multiple high-resolution vertical oxygen profiles across the sediment-water interface. It is equipped with up to nine O_2 electrodes, one conductivity sensor, and one temperature sensor, and is capable of performing multiple vertical sets of up to 15 cm depth along a horizontal distance of 50 cm. The 2-axis fibreoptical profiler will be used to perform multiple deep oxygen profiles. It is equipped with 8 fibreoptical oxygen optodes capable of performing multiple vertical sets of concentration profiles along a horizontal distance of 50 cm. Individual profiles reach total lengths of up to 30 cm. Profiles obtained with both profilers will be used to quantify the rates of diffusive oxygen uptake (DOU) of the sediments, which is generally assigned to microbial respiration, and represents a reliable proxy for organic matter remineralizaion in deep-sea sediments. Furthermore, profiles – especially the ones recorded with the fibreoptical sensors – will be used to determine the penetration depth of oxygen.

The lander-crawler system is a new deep-sea robotic system capable of performing up to 10 measurements along an approx. 100 m long transect. The updated crawler TRAMPER (Wenzhöfer et al. 2016) will be deployed using a moored lander-cage. TRAMPER uses oxygen optodes to measure vertical concentration profiles across the sediment-water interface at each stop. Additionally equipped with a seafloor imaging and scanning camera system (Lemburg et al. 2018), Tramper will take images of the seafloor combined with a laser scan. Using this this information we are able to reconstruct the sediment surface at high resolution. As soon as seafloor images and topography scans are overlaid, we will be able to identify hot spots of intensified organic matter accumulation. These observations are performed during the 10-20 m long transects the system is traveling between consecutive measurements. At the end of each transect, concentration profiles of oxygen are measured across the sediment water interface, which can be used to calculate rates of diffusive oxygen uptake (DOU).

At the first ice station a mooring system (equipped with sediment traps, current meters and pelagic cameras) will be deployed. These measurements will provide an estimate on the amount of organic matter exported to deep waters and settling at the seafloor over the time course of the expedition. Data will be compared with remineralization rates calculated from benthic oxygen consumption rates.

Preliminary (expected) results

Our assessments of benthic biodiversity, function, and biogeochemistry will add to the existing scarce data base of deep-sea and specifically polar regions, and will provide novel insights into the link between sea ice, algal falls and benthic life, including the diversity and distribution of benthic organisms across the central Arctic Ocean under different sea-ice regimes, and in comparison with other deep-sea regions. Comparisons with previous expeditions (e.g. Bienhold et al. 2022; Boetius et al. 2013; Degen et al. 2015; Rapp et al. 2018; Rybakova et al. 2019; Vedenin et al. 2018) will allow insights into the effects of changing environmental conditions on the benthic ecosystem on decadal time scales.

Crawler and lander deployments will provide spatially resolved measurements of organic matter settling on the seafloor between regions of contrasting food supplies, and resolve the impact on the respiration activity of benthic communities at the different sites. Combined with sediment trap and seafloor imaging we expect new insights into the benthic turnover of organic matter under different sea-ice cover in a changing Arctic. The use of new underwater technologies will enhance our capabilities to address the effects of climate change on the Arctic ecosystem. The results will add to our growing database of microbial carbon mineralization in deep-sea (Jørgensen et al. 2022) and polar regions (Boetius et al. 2013) and allow for comparisons over decadal time scales.

In connection with all other teams on board, we aim to disentangle links between sea-ice cover, oceanography, particle flux and benthic diversity and function, to better understand the impact of sea-ice retreat on the entire ecosystem from the surface to the deep sea.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied.

Molecular data (DNA and RNA data) will be archived, published and disseminated within one of the repositories of the International Nucleotide Sequence Data Collaboration (INSDC, www.insdc.org) comprising of EMBL-EBI/ENA, GenBank and DDBJ).

All Sonarwiz 7 and Agisoft Metashape processed map products will be uploaded to MENDELEY DATA for public access within two years of cruise completion.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

This part of the expedition is supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 6, Subtopics 1, 2 and 3.

In all publications based on this expedition, the **Grant No. AWI_PS138_01** or, in case of multidisciplinary work, **AWI_PS138_00** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

Affiliation	**Adress**
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A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
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Allhusen	Erika	DE.AWI	Technician	Biology
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Bienhold	Christina Andrea	DE.AWI	Scientist	Biology
Boetius	Antje	DE.AWI	Scientist	Biology
Böhringer	Lilian	DE.AWI	PhD student	Biology
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Brauer	Jens	DE.NHC	Pilot	Helicopter Service
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Cook	Kathryn	UX.UE	Scientist	Oceanography
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Ernst	Manuel	DE.UFA documentary	Journalist	Public Outreach
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Hoge	Ulrich	DE.AWI	Engineer	Engineering Sciences
Hoppmann	Mario	DE.AWI	Scientist	Oceanography
Horvath	Esther	DE.AWI	Photographer	Public Outreach
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Janssen	Felix	DE.AWI	Scientist	Biology
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Kuznetsov	Ivan	DE.AWI	Scientist	Oceanography
McOscar	Dwayne	DE.DRF	Technician	Helicopter Service
Mehlmann	Carolin	DE.OVGU	Scientist	Mathematics
Miehe	Kai	DE.DRF	Technician	Helicopter Service
Nicolaus	Marcel	DE.AWI	Scientist	Geophysics
Nordhausen	Axel	DE.MPIMM	Technician	Engineering Sciences
Otte	Frank	DE.DWD	Scientist	Meteorology
Oziel	Laurent	DE.AWI	Scientist	Oceanography
Pallentin	Malte	DE.AWI	Engineer	Biology
Purser	Autun	DE.AWI	Scientist	Biology
Quintanilla Zurita	Alejandra	DE.AWI	PhD student	Oceanography
Rabe	Benjamin	DE.AWI	Scientist	Oceanography

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
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Regnery	Julia	DE.AWI	Scientist	Logistics
Richter	Thomas Michael	DE.OVGU	Scientist	Mathematics
Rohde	Jan	DE.AWI	Engineer	Engineering Sciences
Scholz	Daniel	DE.AWI	Engineer	Chemistry
Schulte-Hillen	Ruben Lennart	DE.UNI-FREIBURG	Student (Master)	Biology
Tardeck	Frederic	DE.FIELAX	Technician	Engineering Sciences
Thielecke	Antonia	DE.AWI	PhD student	Biology
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Vane	Kim	DE.AWI	Scientist	Biology
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Vogt	Nils	DE.UFA documentary	Journalist	Public Outreach
Wenzel	Anna Julia	DE.DWD	Scientist	Meteorology
Wenzhoefer	Frank	DE.AWI	Scientist	Biology
Wietz	Matthias	DE.AWI	Scientist	Biology

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

No.	Nachname	Vorname	Position
1	Schwarze	Stefan	Master
2	Lauber	Felix	C/M
3	Hering	Igor	2/M
4	Strauß	Erik	2/M
5	Fallei	Holger	3/M
6	Grafe	Jens	C/E
7	Baehler	Stefanie	2/E
8	Brose	Thomas Christian Gerhard	2/E
9	Beyer	Mario	2/E
10	Dr. Hofmann	Joerg Walter	E/E Com.
11	Kliemann	Olaf	E/E Brücke
12	Zohrabyan	David Rubeni	E/E Labor
13	Redmer	Jens Dirk	E/E SET
14	Nasis	Ilias	E/E System
15	Jaeger	Vladimir	E/E Winde
16	Sedlak	Andreas Enrico	Bosun
17	Münzenberger	Boerge	MPR
18	Klee	Philipp	MPR
19	Schwarz	Uwe	MPR
20	Rhau	Lars-Peter	MPR
21	Meier	Jan	MPR
22	Klinger	Dana Maria	MPR
23	TBN		MPR
24	Kistenmacher	Mario Andre	MPR
25	Cornelsen	Robert	MPR
26	TBN		MPR
27	Haenert	Ove	MPR
28	Neisner	Winfried Wolfgang	Carp.
29	Wende	Uwe	AB
30	Burzan	Gerd-Ekkehard	AB
31	Baecker	Andreas	AB
31	Plehn	Marco Markus	Fitter/E

No.	Nachname	Vorname	Position
32	Matter	Sebastian Udo	Cook
33	TBN		2./Cook
34	Silinski	Frank	2./Cook
35	Wartenberg	Irina	C/Stew.
36	Braun	Maja Alexandra	Stew./Nurse
37	Chen	Qi	2./Stew.
38	Silinski	Carmen Viola	2./Stew.
39	Dibenau	Torsten Karl	2./Stew.
40	Arendt	Rene	2./Stew.
41	Krause	Tomasz	2./Stew.
42	Chen	Dansheng	2./Stew.
43	Goessmann - Lange	Petra	Dr.