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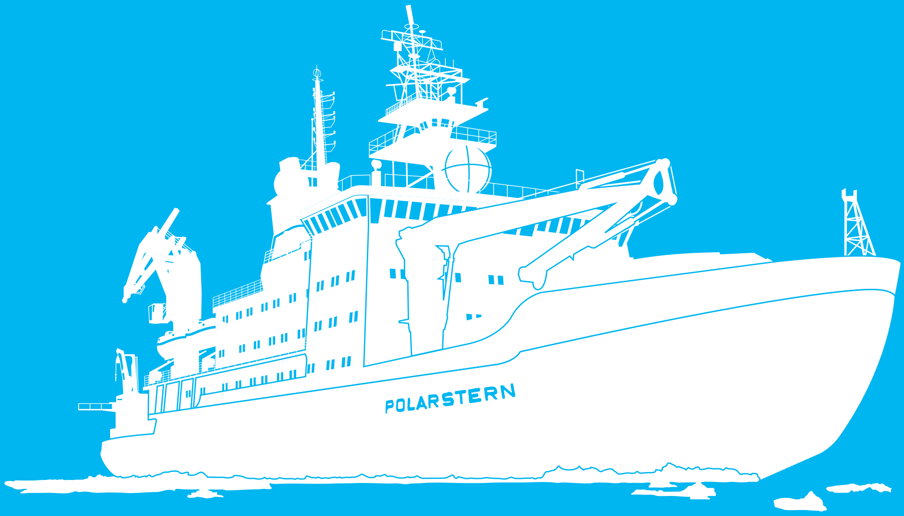
EXPEDITION PROGRAMME PS144

Polarstern

PS144
Tromsø - Bremerhaven
09 August 2024 - 13 Oktober 2024

Coordinator: Ingo Schewe

Chief Scientist: Benjamin Rabe
Co-Chief Scientist: Walter Geibert



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PS144 / ArcWatch-2 (TransArc)

09 August 2024 – 13 October 2024

Tromsø – Bremerhaven

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Contents

1. ÜBERBLICK UND EXPEDITIONSVERLAUF

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Grant-No. AWI_PS144_00

Das Ziel der Expedition ist die großskalige, quasi-synoptische Aufnahme des eurasischen und zentralen Nordpolarmeeres und des Barentsseekontinentalhangs im Nansenbecken. Dies beinhaltet Änderungen über die ganze Tiefe des Ozeans, des Meereises und der unteren Atmosphäre. Änderungen im Jahresgang des Meereises bei sich gleichzeitig verändernden ozeanischen Strömungen in die Arktis und Mustern atmosphärischen Drucks werfen den Bedarf auf, die großskalige Variabilität über die gesamte eurasische Arktis umfänglich zu verstehen. Vorangehende Expeditionen mit diesem Ziel sind unter anderem ArcWatch-1 (2023), TransArc II (2015), TransArc (2011) und SPACE (2007) während des internationalen Polarjahres (International Polar Year IPY); und Beobachtungen durch andere Schiffe während des Synoptic Arctic Survey (SAS) und anderen Expeditionen während des IPY. Die bekannten und zu erwartenden Änderungen reflektieren den Einfluss großskaliger Umweltprozesse und die Beiträge unterschiedlicher Quellen und der Bedingungen am Rand der Arktis. Die Beobachtungen sind Teil eines mehr als 30 Jahre langen Datensatzes, der die Variabilität im dreidimensionalen Raum und in der Zeit widerspiegelt. Unsere Expedition ist die erste Wiederaufnahme in dieser Breite an beobachteten Variablen und mit dieser umfangreichen Abdeckung seit 2015 (TransArc II). Kleinskalige, lokale Umweltprozesse sind auch Teil dieser Expedition und das Vermächtnis vorhergehender Expeditionen, wie das Multidisciplinary Observatory for the Study of Arctic Climate (MOSAiC). Zitate von Fahrtberichten und wissenschaftlicher Literatur sind hier nicht aufgeführt und finden sich in den fachspezifischen Kapiteln 2 – 7.

ArcWatch-2/TransArc ist ein Beitrag zu den internationalen Programmen GEOTRACES, Arctic ROOS/EuroGOOS und dem internationalen arktischen Bojenprogramm (International Arctic Buoy Programme; IABP). Es ist Teil der langfristigen Beobachtungen (Long-Term Observations; LTO) ArcWatch / Arctic Ocean und der Helmholtz programmgebundenen Forschung POF 4 „Changing Earth – Sustaining our Future“, insbesondere Topics 1, 2 und 6. Die Expedition ist ein Vermächtnis des Helmholtz „strategic investment“ Frontiers in Arctic Marine Monitoring (FRAM) und ist ein Beitrag zur Infrastruktur Marine Umweltrobotik und -Sensorik für nachhaltige Erforschung (MUSE).

ArcWatch-2 startet am 9. August 2024 in Tromsø, von wo *Polarstern* nach Longyearbyen (Svalbard, Norwegen) fahren wird. Von dort werden wir eine Teststation nördlich des Archipels anfahren, um dann bei ca. 60°E, 85°N das umfangreiche Stationsprogramm zu beginnen. Voraussichtlich fahren wir zuerst entlang Schnitt II, was auch Eisstationsarbeiten beinhaltet, dann über den Nordpol und entlang 125°W. Einzelne Stationen werden auf dem Transit zu Schnitt III durchgeführt, insbesondere eine Wiederaufnahme der 2015 GEOTRACES Station um 180°E und mehrere Eisstationen. Entlang Schnitt II werden wir dann weitere Eisstationen durchführen und auch in 2023 ausgelegte Verankerungen bergen sowie einen Teil wieder auslegen. Nach dem Transit zu 30°E werden wir den finalen Schnitt I durchführen, bevor wir nach Bremerhaven zurückfahren. Es ist geplant, dass *Polarstern* dort am 13. Oktober

2024 ankommt. Während der Transitfahrten werden wir Beobachtungen des Ozeans, des Meereises und der Atmosphäre vom fahrenden Schiff durchführen, zudem Helikoptereinsätze zu Fernerkundungsmessungen und Arbeiten auf vom Schiff entfernten Eisschollen. Pelagische Netze zum Fischfang werden in Teilen der Schnitte II und III durchgeführt, je nach im Feld messbaren akustischen Rückstreusignalen. Die geplante Vermessung werden vormalig vermessene hydrographische Schnitte mit einer großen Breite von wiederholt gemessenen Variablen wiederaufnehmen und dabei eine großskalige Vermessung eines Großteils des eurasischen Beckens und des Makarovbeckens zur gleichen Jahreszeit ermöglichen (Spätsommer/Frühherbst). Die Schnitte sind quer über die Becken und Rücken rechtwinklig zur längsten Ausdehnung geplant, um somit die arktische Zirkulation quer über bekannte Strömungen und Strukturen zu vermessen. Dies beinhaltet die Transpolardrift zwischen den sibirischen Schelfgebieten und der Framstraße/Grönland.

Änderungen in sowohl der Schichtung des oberen Ozeans als auch des Meereises sind Teil der Atlantifizierung (engl. „Atlantification“), wobei die Bedingungen im eurasischen Teil des Nordpolarmeeres sich denen im Nordatlantik annähern, zusammen mit Änderungen im zeitlichen Ablauf von Meereisbildung und -schmelze. Dies, wiederum, führt zu Rückkopplungen mit der Zirkulation im flüssigen Ozean und dem Meereis, in engem Zusammenhang mit der Verteilung von verschiedenen Substanzen, wie Makronährstoffen, Spurenelementen und deren Isotope sowie verschiedenen Tracern (Spurenstoffe, die als Fingerabdruck biogeochemischer und physikalischer Prozesse dienen). Gemessen werden in diesem Zusammenhang unter anderem chlorierte und fluorierte Kohlenwasserstoffe (CFC), Mikronährstoffe, eine große Bandbreite an Elementen und ihren Isotopen, natürliche und künstliche Radionuklide als Zeitmarker sowie Stoffe mit potenziell schädlicher Wirkung wie Blei und Quecksilber. Einige sind passive Spurenstoffe, während andere Teil von Wechselwirkungen mit der biogeochemischen Umgebung und dem Ökosystem sind. Die Quelle dieser Substanzen reicht von lokalem Niederschlag bis zu Kontinentalabfluss und Austausch mit den Ozeanen niederer Breiten, womit sie zum Nachweis von Veränderungen in diesem Bereich dienen können. Eine Aufnahme der Meereisdicke und -verteilung geht der kontinuierlichen Verringerung der arktischen Meereisbedeckung nach. Zusätzlich werden die Beobachtungen helfen, die meereisbezogene Satellitenfernerkundung zu verbessern, indem lokale Oberflächenabstrahlung und einzelne Merkmale, wie Schmelztümpel, untersucht werden. Eine umfangreiche Aufnahme des Ökosystems wird die genetischen Merkmale kleiner Tiere, die Verteilung von planktonischen und sympagischen Arten bis zum Lebensraum und dem Verhalten größerer Organismen, wie dem Polardorsch, beinhalten. Ein wichtiger Aspekt ist hier der Bergleich ähnlicher Beobachtungsdaten in anderen Teilen der Arktis, wie der Beringsee. Die Umgebung, insbesondere das Meereis, wird auch beprobt und ist ein wichtiger Teil dieser Aufnahme. Zusätzlich zu unserem verbesserten Verständnis des zeitgenössischen Ökosystems werden die Messungen auch helfen, paläoozeanographische Messungen zu interpretieren. Atmosphärische Beobachtungen konzentrieren sich auf Wolken, Niederschlag, Windgeschwindigkeit, einfallende Sonnenstrahlung und Aerosole. Viele unserer Messungen werden räumlich und zeitlich wesentlich durch autonome, driftende und meereisbasierte Bojen erweitert.

Die Expedition wird auch genutzt werden, um weiterentwickelte Beobachtungen (Drohnen) zusammen mit Meereisinformationen aus Satellitendatenprodukten und der operationellen Aufnahme der regionalen Meereisbedingungen zu testen, um die Navigation in Polargebieten zu verbessern.

SUMMARY AND ITINERARY

The aim of this expedition is the large-scale, quasi-synoptic assessment of the eurasian / central Arctic Ocean and the Barents Sea continental slope in the Nansen Basin. This includes changes throughout the full-depth ocean, the sea ice and the lower atmosphere. Changes in the seasonal cycle of sea ice amid varying atmospheric pressure patterns and ocean inflows prompt the need to thoroughly understand large-scale variability across the Eurasian Arctic. Prior expeditions that have followed the same aim include ArcWatch-1 (2023), TransArc II (2015), TransArc (2011) and SPACE (2007) during the International Polar Year (IPY); and observations by other ships during the Synoptic Arctic Survey (SAS) and other IPY expeditions. The known and expected changes mirror the impact of large-scale environmental processes, and the contributions from different sources and conditions at the Arctic boundaries. The observations form part of a more than 30 years long data set that manifest variability in three-dimensional space and in time. Our expedition is the first reassessment with a comprehensive breadth of observed variables and with a wide spatial coverage since 2015 (TransArc II). Smaller-scale, local environmental processes also form a part of this expedition and follow in the legacy of prior expeditions, such as the Multidisciplinary Observatory for the Study of Arctic Climate (MOSAiC). References to the cruise reports and the scientific literature are not given here; instead, the reader is referred to the Chapters 2 – 7 for each discipline.

ArcWatch-2/TransArc is a contribution to the international programmes GEOTRACES, Arctic ROOS/EuroGOOS and the International Arctic Buoy Programme (IABP). It is part of the Long-Term Observations (LTO) ArcWatch / Arctic Ocean and the Helmholtz programme oriented research POF 4 “Changing Earth – Sustaining our Future”; in particular, Topics 1, 2 and 6. The expedition forms a legacy to the Helmholtz strategic investment Frontiers in Arctic Marine Monitoring (FRAM) and forms a contribution to the infrastructure Marine Umweltrobotik und -Sensorik für nachhaltige Erforschung (MUSE; marine environmental robotics and sensors for sustainable exploration).

ArcWatch-2 sets off in Tromsø on 9 August 2024, with *Polarstern* sailing to Longyearbyen (Svalbard, Norway). From there we will move toward a test station north of the archipelago and start the full programme of station work at 60°E around 85°N, likely continuing along Section II, including ice station work, across the North Pole and along 125°W. A few individual stations will be carried out along the transit to Section III, in particular, a revisit to a 2015 GEOTRACES station around 180°E and several ice stations. Along section III we will then carry out further ice stations and mooring operations to recover moorings deployed in 2023 and partial re-deployment. After transiting toward 30°E we will carry out the final Section I, before returning to Bremerhaven, where *Polarstern* is scheduled to arrive on 13 October 2024. Throughout the transits we will carry out underway observations of the ocean, the sea ice and the atmosphere; and helicopter operations for remote sensing and work on ice floes away from the ship. Pelagic net trawls for fish will be carried out in parts of Sections II and III, depending on the *in situ* acoustic backscatter signal. The planned surveys will recapture previously covered hydrographic sections with a large set of repeatedly measured variables while allowing a large-scale survey of much of the Eurasian and Makarov basins in the same season (late summer/ early autumn). Sections are planned to cross basins and ridges perpendicular to the most elongated expansion, thus surveying Arctic circulation across known currents and structures; this includes the Transpolar Drift between the Siberian shelves and the Fram Strait/Greenland.

Changes in both upper ocean stratification and sea ice are subject to Atlantification, whereby conditions in the Eurasian Arctic Ocean approach those of the North Atlantic, along with changes in the timing of sea-ice formation and melt. This, in turn, feeds back with liquid ocean and sea-ice circulation, closely related to the distribution of various substances, such as macronutrients, trace elements and their isotopes, and a set of tracers, including Cluorofluorocarbons (CFC), micronutrients, naturally occurring and anthropogenic radioisotopes as time markers, and potential pollutants, such as lead and mercury. Several of these are passive tracers, whereas others interact with the biogeochemical environment and the ecosystem, making them powerful tracers of related changes. The sources of these substances range from local precipitation to continental runoff and exchanges with lower-latitude oceans. An assessment of sea-ice thickness and distribution will follow-up on the ongoing decrease of the Arctic sea-ice cover. An additional benefit of the observations will help improve satellite remote sensing around the sea ice by looking at the local surface emissivity and specific features, such as melt ponds. A comprehensive assessment of the ecosystem will include the genetics of small animals, the distribution of planktonic and sympagic species up to the habitats and behaviour of larger organisms, such as polar cod. An important aspect here is the comparison to similar observational data in other parts of the Arctic, such as the Bering Sea. The environment, in particular, the sea ice, will also be sampled and forms an important part of this assessment. In addition to improve our understanding of the contemporary ecosystem the measurements also help to improve the interpretation of palaeoceanographic records. Atmospheric observations focus on clouds, precipitation, wind speed, incoming solar radiation and aerosols. Many of our observations will be significantly extended in space and time by autonomous drifting buoys tethered to the sea ice.

The expedition will also be used to test advanced observations (drones) together with sea-ice information from satellite products and an operational assessment of the regional ice conditions to improve navigation in polar regions.

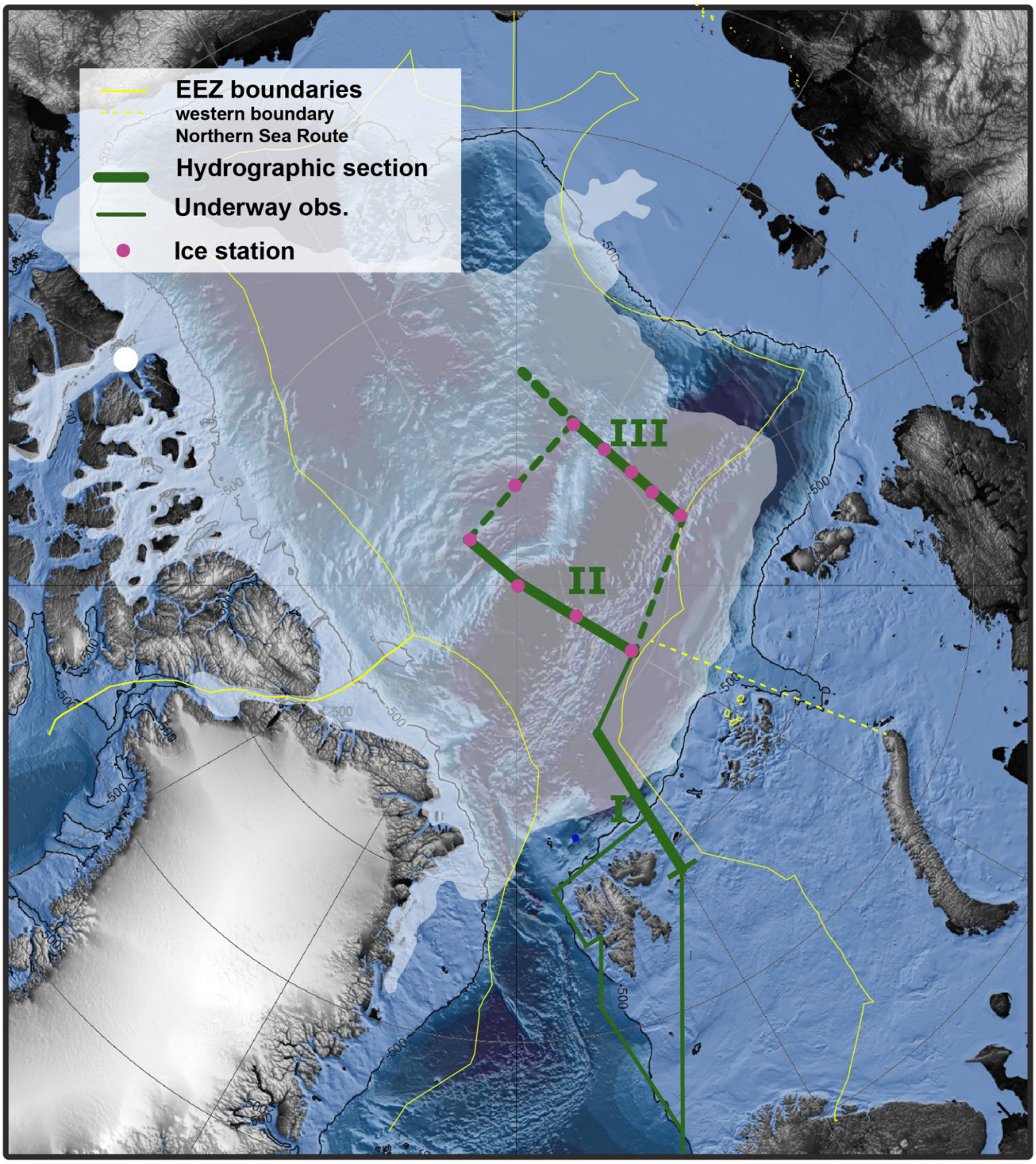

Abb. 1: Geplante Fahrtroute und Stationen sowie hydrographische Schnitte I – III der Expedition PS144 (ArcWatch-2/TransArc). Die Reise beginnt am 9. August 2024 in Tromsø und endet am 13. Oktober 2024 in Bremerhaven. Genaue Positionen der Eisstationen und anderer Aktivitäten werden vor Ort geplant. Der genaue Verlauf der Reise ist abhängig von der Eis- und Wettersituation zwischen August und Oktober 2024.

Fig. 1: Planned cruise track and stations as well as hydrographic sections I – III of the expedition PS144 (ArcWatch-2/TransArc). The expedition starts on 9 August 2024 in Tromsø and ends on 13 October 2024 in Bremerhaven. Exact positions of ice stations and other activity will be planned in situ. The exact cruise track will depend on ice and weather conditions from August to October 2024.

2. MARINE GEOCHEMISTRY (MGC)

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Objectives

Introduction

While the importance of trace elements for biota and as tracers in the ocean has long been recognized, the ability to measure the most contamination-prone of them only developed in the last decades. In the following decades, a large assessment of the global distribution of trace elements and their isotopes (TEIs) evolved, internationally organized and co-ordinated in the GEOTRACES programme (www.geotraces.org). This programme aims at producing section studies and process studies of the world's oceans that cover the most important water masses and processes, with pre-defined sampling, intercalibration and data reporting requirements. As an exception, the Arctic Ocean is now covered for the second time by the GEOTRACES programme, also building on previous cruises in the International Polar Year, recognizing its particularly sensitive nature to warmer temperatures. The marine geochemistry team covers very diverse tracers with vastly differing sampling requirements, which is why they are described in sections by the individual sub-teams below. The work is closely connected to other working groups, in particular BTM, MBC and PO. The AWI trace-metal clean CTD is a relatively new addition to the pool of sampling devices at AWI, and it is run here in a collaborative effort by scientists from GEOMAR and AWI, joined by other national and international expert groups that are presented below.

Aerosol trace metals and major ions

Atmospheric deposition is an important source of nutrients to the open ocean (Hamilton et al., 2022). Advection of air masses across the shelf break has the potential to connect the continental interior to nutrient demand in remote ocean regions. Although Arctic Ocean productivity does not usually depend on aerosol deposition, recently it has been suggested that Siberian forest fires and long-range transport of smoke increased offshore productivity in the Eurasian Basin in summer (Ardyna et al., 2022). On the contrary, aerosols advected from lower latitudes may also carry a significant load of (natural or anthropogenic) pollutants to the Arctic (Law and Stohl, 2007). High concentrations of aerosol pollutants including lead, copper and cadmium are typically observed in winter and spring ('Arctic haze') (De Vera et al., 2021;

Gong and Barrie, 2005), however, local sources and long-distant transport of pollutants may also be present in summer (Conca et al., 2019). During PS144, we will sample for bioessential (i.e. Fe, Mn, Co, Ni, Cu, Zn, Cd) and pollutant (i.e. Cd, Pb, As) aerosol trace metals and aerosol major ions (i.e. Na^+, Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}) along its cruise track. It is our aim to investigate the source regions of aerosols and its impact on primary production in the Eastern Arctic Ocean. Through dissolution experiments, we will determine the fraction of aerosol trace metals and macronutrients that are potentially available to phytoplankton in late summer.

Nutrient addition bioassay experiments

The Arctic Ocean has seen an increase in primary production of ~57% between 1998 and 2018 (Lewis et al., 2020), which is most likely supporting higher trophic levels and enhanced carbon export. However, little is known about the factors that controls phytoplankton growth in the Arctic. While there is evidence for light and fixed nitrogen (N) being the primary factors controlling phytoplankton growth in the western parts of the Arctic Ocean (Mills et al., 2018; Ortega-Retuerta et al., 2012), with evidence of phytoplankton co-limitation by light, fixed N and the micronutrient Fe in late summer (Taylor et al., 2013), experimental evidence on the nature of surface phytoplankton nutrient limitation is missing for the Eastern and Central Arctic Ocean. In the scope of PS144, we aim to provide experimental evidence on the nature of phytoplankton nutrient limitation through the conduction bioassay (nutrient addition) experiments, testing for Fe, N or Fe/N (co-)limitation of phytoplankton growth along the cruise track. Major aim of the experimental work on-board is to quantify the response of phytoplankton growth (measured as Chlorophyll-a) to additions of potentially limiting nutrients, and establish relationships to prevailing water masses in the Eastern and Central Arctic Ocean.

Dissolved and particulate trace metals (Fe, Mn, Co, Ni, Cu, Zn, Cd)

The Arctic Ocean is subject to considerable change due to anthropogenic climate forcing (Meredith et al., 2019). Although the Arctic Ocean has seen an increase in primary production of ~57% between 1998 and 2018 (Lewis et al., 2020), little is known about the factors that drive this increase in phytoplankton growth, including micronutrient availability. Enhanced riverine discharges (Feng et al., 2021), increased shelf erosion and offshore transport of sediment material (Kipp et al., 2018), sea-ice decline (Spreen et al., 2008) and an ‘Atlantification’ of large parts of the Eastern Arctic Ocean (Polyakov et al., 2017; Wang and Danilov, 2022) have ramifications on trace metal cycling and micronutrient availability also in the region downstream to the Arctic Ocean including the Greenland Sea (Krisch et al., 2022).

With PS144, we aim to assess the changes in sources, cycling and sinks of dissolved micronutrients against previous expeditions from 2007 (PS70) and 2015 (PS94, ‘TransArc 2’). It is the aim of our work to extend the timeline of Arctic Ocean micronutrient cycling at a sub-decadal resolution which we deem is crucial for the projection of future ecosystem services including primary production, carbon sequestration and food web structure in the Central Arctic and high-latitude North Atlantic Ocean.

With PS144, we aim to assess the changes in sources, cycling and sinks of dissolved micronutrients against previous expeditions from 2007 (PS70) and 2015 (PS94, ‘TransArc 2’). It is the aim of our work to extend the timeline of Arctic Ocean micronutrient cycling at a sub-decadal resolution which we deem is crucial for the projection of future ecosystem services including primary production, carbon sequestration and food web structure in the Central Arctic and high-latitude North Atlantic Ocean.

In the scope of PS144, our objectives are:

- Determining the horizontal and vertical distributions of the dissolved and particulate (labile and refractory) fractions of Fe, Mn, Co, Ni, Cu, Cd and Zn in the Eastern and Central Arctic Ocean to full depth.
- Investigating into sources, cycling and sinks of dissolved Fe, Mn, Co, Ni, Cu, Cd and Zn.
- Quantifying lateral and vertical export fluxes of the dissolved trace metals dFe, dMn, dCo, dNi, dCu, dZn, dCd, and dPb across two sections following the advection of the Transpolar Drift.
- Quantifying nutrient stoichiometries and investigating the extent of late summer fixed N and dFe deficiencies in the Central and Eastern Arctic Ocean relative to typical phytoplankton requirements.

Dissolved Fe isotopic composition (δ^{56}dFe)

The Arctic Ocean is subject to considerable change due to anthropogenic climate forcing (Meredith et al., 2019). This change manifests itself in enhanced riverine discharges (Feng et al., 2021), increased shelf erosion and offshore transport of sediment material (Kipp et al., 2018), sea ice decline (Spreen et al., 2008) and an 'Atlantification' of large parts of the Eastern Arctic Ocean (Polyakov et al., 2017) all of which have ramifications on Fe cycling and Fe availability. Through the use of the natural isotopes ^{54}Fe, ^{56}Fe, ^{57}Fe and ^{58}Fe, it is possible to investigate the provenance of dFe to the water column and trace key aspects of oceanic Fe cycling such as biological uptake, particle scavenging and speciation changes (Fitzsimmons & Conway, 2023).

In the scope of PS144 we aim to

- Characterise surface Fe-transport,
- Investigate biological drawdown and abiotic scavenging of dFe
- Calculate the relative contribution of hydrothermal venting, reductive and non-reductive sedimentary release to the dissolved pool in the Eastern and Central Arctic Ocean.

Special emphasis is put on the characterisation of sources and Fe cycling to the Nansen Basin and surface waters of the Transpolar Drift.

Rare earth element concentrations and neodymium isotopes

The unique conditions in the Arctic of input, removal, and exchange processes in relation to particle composition, particle fluxes, and circulation are acting on trace element and isotope distributions in the Arctic Ocean. Particularly, cruise PS94 to the Central Arctic showed that dissolved rare earth element (REE) concentrations are exceptionally high in the Transpolar Drift (TPD), and the dissolved Nd isotope composition allows differentiation of the freshwater contributions to the TPD from the different Siberian rivers and Atlantic water (Paffrath et al., 2021a). These contributions and trace metal and isotope distributions are potentially sensitive to the environmental changes affecting the Arctic. We propose, that the increasing influence of Atlantic water in the Arctic ('Atlantification') will be visible in the Nd isotope signature in the Central Arctic in 2024 in comparison to 2015. Additionally, the catchment areas of the large Siberian rivers Lena, Yenisei and Ob are marked by different permafrost conditions that will react differently to increasing warming. We suggest that Nd isotopes and REE in the TPD will trace these changes (in comparison to 2015).

Gallium

The Arctic Ocean is responding to changes in Atlantic water inflow, the effects of which have resulted in destabilization of the halocline in some regions of the Eurasian basin (Polyakov et al., 2023). During PS144, we plan to collect samples for dissolved gallium. We will combine these new samples with analysis of stored samples to build and interpret a pan-Arctic, temporally rigorous gallium dataset. Gallium was demonstrated to have significant differences in Pacific and Atlantic waters (McAlister and Orians, 2015; Whitmore et al., 2020). These differences (low concentrations in Pacific-derived waters and high in Atlantic-derived waters) were utilized to predict the fractions and distribution of water masses in the western Arctic Ocean (Whitmore et al., 2020), with the result that the Ga method predicted greater abundance of Pacific-derived seawater than the traditionally used nutrient deconvolutions (e.g., Whitmore et al., 2020; Newton et al., 2013). This project will address the primary questions: Does gallium distribution in the Eurasian basin indicate any substantive change over a decadal fingerprint (i.e., compare spatial distribution and concentration between 2015 and 2024 data)? We will affirm the conservative nature of gallium in the region and leverage it in a multi-tracer approach to deconvolve different water masses in the Eurasian basin.

Mercury

Arctic biota is highly contaminated with mercury (Hg), when compared to mid-latitude biota, putting the health of the ecosystem and indigenous peoples at risk (AMAP Assessment 2021, 2021). This is a surprising fact, since no known anthropogenic Hg sources exist in the Arctic. Fisher et al. (2012) questioned the role of the Siberian rivers in Hg supply to the Arctic Ocean and Sonke et al. (2018) constrained a river flux to 44 t/y. In the following, the arctic Hg budget was evaluated with 1900 Mg and about 200 Mg/y inputs and outputs (Petrova et al., 2020). Many of the estimates are associated with large uncertainties that require further research. It is clear though, that the short Hg residence time (10 years) makes the Arctic Ocean particularly sensitive to external changes. The Arctic Ocean receives Hg from the atmosphere (Steffen et al., 2008), rivers (Sonke et al., 2018), exchange with other oceans (Petrova et al., 2020). The largest removal mechanism is the vertical export with settling particles (Tesán-Onrubia et al., 2020).

The Arctic Ocean is the only ocean with elevated Hg levels in surface waters and shallow MeHg (Heimbürger et al., 2015). The shallow MeHg may explain in part the elevated biota Hg levels (Wang et al., 2019). The shift from multi year ice (MYI) to first year ice (FYI) has increased sea ice MeHg concentrations (Schartup et al., 2020). Preliminary data from 2018/19 show higher total Hg concentrations in the MYI and a large accumulation of MeHg in the seawater under the MYI, possibly enhancing MeHg bioaccumulation locally. Kohler et al. (2023) refined the rctic budget with a seasonal cycle of Hg in the arctic budget questioning the previously established arctic Hg budget. Adding to this uncertainty of the current state of Hg biogeochemistry, climate change is expected to affect the Arctic Ocean Hg budget by reducing sea ice cover, permafrost, and increasing riverine discharge. PS144 will allow us to get the first ever long term observations starting in 2011 (Dastoor et al., 2022; Heimbürger et al., 2015; Petrova et al., 2020), allowing us to investigate possible changes over time.

In the scope of PS144, our objectives are:

- Determine horizontal and vertical distributions of total, dissolved, and particulate Hg.
- Investigating Hg sources, cycling, and sinks across the three sections from the Central to the Eastern Arctic Ocean.
- Quantifying Hg speciation and transfer along the different compartments.
- Test for possible long-term trends in Hg burden in the AO.

Natural radionuclides (^{230}Th, ^{231}Pa, ^{232}Th, ^{226}Ra, ^{228}Ra)

The naturally occurring radionuclides of the uranium and thorium (U/Th) decay series are unique tools in oceanography because of their exactly known source and loss terms from laws of radioactive decay. Therefore, they can serve as a time marker whenever they are redistributed in the ocean, measuring their integrated response to marine processes. This has made some of them key parameters of the GEOTRACES programme, for example as tracers of ocean circulation, shelf-ocean exchange, or export production. In the Arctic Ocean, which is hardly or not at all accessible to continuous observation, they have proven to be particularly useful tracers for constraining the integrated rate of processes.

In particular, these U/Th series tracers are of use in the Arctic Ocean:

- ^{230}Th and ^{231}Pa serve as markers for deep water circulation and particle flux in the Central Arctic Ocean(Valk et al., 2020). In addition, they are used as proxies for past ocean circulation in sediments.
- ^{232}Th as a tracer for terrigenous input, providing information similar to other lithogenic trace metals like Al or Ti, but chemically identical to ^{230}Th that has a known source.
- ^{228}Ra as a tracer for shelf input, which has been shown to increase substantially due to the warming Arctic (Rutgers van der Loeff et al., 2018; Rutgers van der Loeff et al., 1995);
- ^{226}Ra provides information on deep water circulation, in particular when combined with Ba that can serve as a stable analogue (Le Roy et al., 2018). With newly achievable precision analyses (Vieira et al., 2021), ^{226}Ra may also trace slope contact. It also serves as a yield tracer for ^{228}Ra. Ba is also delivered by riverine input (Roeske et al., 2012), possibly ^{226}Ra as well.

We therefore aim to analyze the dissolved distribution of ^{230}Th, ^{231}Pa, ^{232}Th, and the distribution of total ^{226}Ra and Ba in full depth profiles; the total ^{228}Ra/^{226}Ra ratio on surface samples and selected large-volume stations. Additionally, the particulate ^{230}Th, ^{231}Pa and ^{232}Th profiles on selected deep-water stations.

This work is closely linked to the determination of C-export via ^{234}Th by beta-counting (BTM group) following methods of Roca-Martí et al. (2016).

Our objective it to compare these data to existing analyses to investigate the presence of absence of recent changes.

Dissolved Pb, particulate Pb (labile, refractory) and Pb isotopic composition

Pb is a toxic element (Wani et al., 2015), the natural cycling of which has been markedly affected by anthropogenic emissions such as from burning coal and leaded gasoline (Boyle et al., 2014). The North Atlantic Ocean is among the regions most affected by aerosol Pb deposition (Boyle et al., 2014; Zurbrick et al., 2018). Northward advection of Atlantic Waters (Tsubouchi et al., 2021), enriched in dPb (Schlosser & Garbe-Schönberg, 2019), may cross into the Arctic Ocean and lead to widespread Pb deposition along its flow path. An additional source of Pb to the surface Arctic Ocean is derived from atmospheric deposition (Conca et al., 2019). Both sources, marine and atmospheric, may result in elevated Pb levels in Arctic marine biota (Schulz-Baldes & Lewin, 1976; Zimmer et al., 2011).

PS144 (“TransArc III”) aims to investigate the Pb cycling in the Eastern and Central Arctic Ocean and the current extent of perturbations from past Pb emissions. Specific emphasis is put on the investigation into the areal extent and changes to the northward advection of dPb from Atlantic Water between 2015 ("TransArc II") and 2024 ("TransArc III"). This will be achieved by reoccupying stations from the previous 2015 campaign. We will investigate the efficiency of dPb transport from Siberian Shelf sources towards the Central Arctic Ocean by sampling transects in the Transpolar Drift at various distances from the shelf break. Through analyses of Pb isotopic composition, we aim to identify natural and anthropogenic sources of Pb in the water column, as has been previously achieved for the Western Arctic Ocean (De Vera et al., 2021).

Transient Tracers (^{14}C, ^{39}Ar, ^{129}I, ^{236}U)

The world's oceans are responding to the anthropogenically induced climate change, with the Arctic Ocean standing out as one of the most rapidly changing regions. A phenomenon known as Arctic 'Atlantification', linked to the melting sea-ice and influencing the Atlantic Meridional Overturning Circulation (AMOC), remains poorly understood. Bridging this knowledge gap requires intensified measurement and modeling efforts. To address this need, long-lived radionuclides of both natural and artificial origin (i.e. ^{129}I, ^{236}U, ^{14}C and ^{39}Ar) are excellent tools that bring insight to ocean circulation and ventilation processes. PS144 offers the unique opportunity to sample water masses in the Central Arctic Ocean one decade after TransArc2 providing valuable insights into alteration in water mass circulation and its relation to climate change.

In the scope of PS144, we will tackle the follow research questions:

1. What is the distribution of ^{129}I, ^{236}U, ^{14}C and ^{39}Ar in the central Arctic Ocean (2024) and how does it compare (when previous data exist) to the snapshot taken 2015?
2. What are the pathways, circulation timescales and mixing regimes of Atlantic-origin waters in 2024 and how do they compare to 2015?
3. What are the ventilation timescales of deep water in the Central Arctic Ocean and how do these compare to previous estimates done in the 1990s?
4. How do changes (if any) relate to Arctic Atlantification?

Work at Sea

Aerosol trace metals and major ions

The high volume aerosol sampler (MCV CAV-A/Mb) will be placed on the A-deck for collection of trace elements and major ions. The unit will be operated full-time and sample for aerosols with a flow rate of 1 m^3/min along the entire cruise track at a time resolution of 3-5 days. An automatic control system checking the wind direction and wind speed will prevent from the risk of contamination through the ship's exhausts. Acid-washed ~20 x 25 cm Whatman 41 filters will used to collect aerosol particles. Samples will be frozen immediately after collection and stored at -20°C in the dark until analysis.

Nutrient addition bioassay experiments

The incubation experiments at sea will be conducted following the procedure previously established on PS100 in Fram Strait (Krisch et al., 2020).

Seawater for the conduction of incubation experiments will be collected at 10 m depth using the AWI trace metal clean CTD rosette equipped with trace metal clean Go-Flo bottles following GEOTRACES sampling protocols (Cutter et al., 2017). Incubation experiments will be carried out in 1L trace-metal clean polycarbonate bottles. Each set of nutrient amendments (+N, +Fe,

+N+Fe) will be carried out in triplicate. One set of triplicate bottles will be incubated without any nutrient addition and function as control. Three additional bottles without nutrient addition will be sampled immediately after bottling to record the initial conditions. Bottles are placed in an on-deck incubator (shaded with blue screening to yield incubator light intensities of ~35% of surface values) which will be connected to the ships underway flow-through system to maintain the temperatures as in surface waters. The incubation will be carried out for 96 hours. Bottles are manually stirred to mirror ocean wave action. After incubation, bottles (initial and incubated) are filtered on a glass fibre filter to retain Chlorophyll-a. In addition, all remaining seawater in the triplicate replicate bottles will be pooled and filtered onto a glass fibre filter to be analysed for phytoplankton pigment concentrations by HPLC (that is producing one sample per treatment). The filters are stored in the dark and frozen at -80°C immediately after sampling. Concentrations of chlorophyll-a (measured by fluorometry following acetone extraction), and pigment composition (indicative of phytoplankton species contributions; measured by HPLC) will be measured at GEOMAR.

Dissolved and particulate trace metals (Fe, Mn, Co, Ni, Cu, Zn, Cd)

We aim to sample around 40 stations selected based on *in situ* water mass properties (e. g. nutrient regimes, prevailing currents), occurrence of phytoplankton blooms or post-bloom conditions, or important trace metal sources and sinks (e.g. hydrothermal, shelf slope, sea-ice, riverine sources). Stations will be sampled at high-resolution and to full depth for dissolved, and labile particulate and refractory particulate trace metals and macronutrients (nitrate, nitrite, ammonium, phosphate and silicic acid) using the AWI contamination-free titanium CTD rosette (KUM, equipped with a SBE 911 CTD) equipped with 24 trace metal clean Go-Flo bottles following GEOTRACES sampling protocols (Cutter et al., 2017). Subsampling from GoFlo bottles will be conducted in AWI's class-100 clean-room container immediately after the CTD deployment. Samples for dissolved trace metals will be filtered through 0.8/0.2 µm Acropak cartridge filters (Pall corporation) into 125 mL trace metal clean LDPE bottles and acidified to pH 1.9 through addition of ultra-pure hydrochloric acid (ROMIL) immediately after sampling. Samples for the particulate trace metal fractions will be collected on 0.2 µm filters (Millipore) with slight over-pressure with clean-air filtering at least 4 L of seawater. Particulate samples are frozen at -80°C immediately after sampling. Macronutrient samples remain unfiltered and will be refrigerated and analyzed within 12 hours on-board by Sinhué Torres-Valdés following well-established methods (see Chapter 5). Dissolved and particulate samples will be shipped to GEOMAR for analysis.

Dissolved Fe isotopic composition (δ^{56}dFe)

Samples will be collected using the AWI's trace metal clean CTD rosette equipped with trace metal clean Go-Flo bottles following GEOTRACES sampling protocols (Cutter et al., 2017). We aim to sample 12 stations at 10 depth intervals to full depth, yet with greater vertical resolution of the upper water column (< 200 m depth) which will help us to constrain the provenance and internal cycling processes of dFe such as biological uptake and scavenging (Fitzsimmons & Conway, 2023). Samples will be filtered through 0.8/0.2 µm Acropak cartridges (Pall corporation) into 1 L or 2 L trace metal clean LDPE bottles and acidified to pH 1.9 through addition of ultra-pure hydrochloric acid (ROMIL) immediately after sampling. Samples are stored in the dark and shipped to the University of South Florida for analysis.

Rare earth element concentrations and neodymium isotopes

Dissolved REE and Nd isotopes: Water column sampling will be conducted of the upper 1,000 m at the GEOTRACES stations of PS94 plus stations in between for dissolved REE and Nd isotopes. Additionally, we will conduct full water column sampling at selected stations including, if possible, reoccupations of PS94-125 (85.0855°N, 139.9787°E) and/or PS94-134 (84.8443°N, 159.0247°E), where unexpected and extremely high positive gadolinium anomalies (pointing towards anthropogenic contamination) were found at different depths down to 3,500 m in 2015 (Paffrath et al., 2021b), and at GEOTRACES crossover station PS94-101 (87.4973°N, 179.8412°E).

Sampling for REE and Nd isotopes will be realized by direct filtration of seawater from Niskin bottles using AcroPak500 cartridges (0.8/0.2 µm pore size). For dissolved Nd isotope samples we require 5 L per sample, for REE concentrations we will collect 50-100 mL, depending on sample availability. Samples will be acidified to pH 3.5 (Nd isotopes) and pH 2 (REE) using 6N ultra-clean hydrochloric acid. Samples for Nd isotopes will be preconcentrated onboard using C18 cartridges (Waters Inc.) filled with a complexing agent.

Particulate REE and Nd isotopes: If available, we will collect particles from *in situ* pumps from the upper 1,000 m for REE and Nd isotope measurements.

Gallium

To be able to establish a timeline of change, we aim to resample as many PS94 stations as possible. Samples will be taken from the trace metal clean CTD equipped with GoFlo bottles. Sample handling will be conducted in the AWI clean-room container. We will sample the water column to full depth at least 18 depths. Samples will be filtered using 0.8/0.2 µm Acropak catridges (Pall cooperation) into 60 mL bottles. Samples will be tightly closed, stored in doubled bagged plastic and stored dark & in totes until return to the shore-based laboratory.

Mercury

Seawater will be sampled from the trace metal clean carousel at every station and to full depth. Unfiltered total Hg will be bottled into trace metal clean Teflon bottles and acidified with ultra-pure hydrochloric acid (ROMIL) immediately after sampling. These samples will be measured via cold vapor atomic fluorescence spectroscopy (CVAFS; BROOKS Rand Model 3) at MIO. From an aliquot of tHg samples, we will purge off dissolved gaseous mercury (DGM = Hg0 + DMHg). The DGM-purged sample will be acidified for monomethylmercury (MMHg) analysis back at MIO. Total methylmercury (MeHg = MMHg + DMHg) will be sampled into Teflon bottles and acidified with ultra-pure hydrochloric acid (ROMIL) immediately after sampling. Particulate Hg (pHg) and particulate monomethylmercury (pMMHg) will be sampled onto GFF filters using in line bottle-filtration, as well as from sediment cores, and plankton samples. pHg will be measured via cold vapor atomic absorption spectroscopy (CVAAS; LECO AMA254). MeHg, MMHg and pMMHg will be analyzed via species specific isotope dilution gas chromatography sector field ICP-MS (THERMO GC 1300 with Element XR). In order to investigate MMHg biomagnification, we will also take samples – where possible – from glacial ice, sea ice, phytoplankton, zooplankton and biota.

Natural radionuclides (^{230}Th, ^{231}Pa, ^{232}Th, ^{226}Ra, ^{228}Ra)

We aim to take up to 360 samples for ^{230}Th and ^{231}Pa (dissolved) from full depth stations (regular CTD); up to 360 samples for total ^{226}Ra from full depth stations; up to 360 samples for ^{232}Th (dissolved) and Ba (clean CTD); up to 120 samples for ^{228}Ra/^{226}Ra ratios in manganese-dioxide adsorbers (upper water column); up to 64 filter samples for ^{231}Pa and ^{230}Th (*in-situ* pumps or large-volume CTD bottle samples, depending on availability). Most of the analysis will be done in the home laboratory, except ^{234}Th in collaboration with the BTM group.

Dissolved Pb, particulate Pb (labile, refractory) and Pb isotopic composition

Samples for dissolved and particulate Pb will be obtained by using the AWI trace metal clean CTD rosette equipped with 24 trace metal clean Go-Flo bottles following GEOTRACES sampling protocols (Cutter et al., 2017). We aim to sample the water column at 18 depth intervals to full depth. The upper 1,000 m will be sampled in higher vertical resolution as those incorporate Atlantic Water masses, low salinity surface waters from the East Siberian Shelf (Transpolar Drift) and regions of elevated productivity (as indicated by *in-situ* fluorescence measurements). To monitor change in Pb cycling between 2015 and 2024, we aim to reoccupy as many stations from TransArc II as possible.

Samples for dissolved Pb will be filtered through a 0.8/0.2 µm Acropak cartridge filter (Pall corporation) into 125 mL trace metal clean LDPE bottles and acidified to pH 1.9 through addition of ultra-pure hydrochloric acid (ROMIL) immediately after sampling. Samples for measurements of dissolved Pb isotopic composition will be passed through a 0.8/0.2 µm Acropak cartridge filter (Pall corporation) into 1 L trace metal clean LDPE bottles and acidified to pH 1.9 through addition of ultra-pure hydrochloric acid (ROMIL) immediately after sampling. Samples for the particulate fractions of Pb (labile particulate, refractory) and for measurements of isotopic composition of particulate Pb will be collected on 0.2 µm filters (Millipore) filtering at least 4 L of seawater. Particulate samples are stored in the dark at 80°C.

Transient Tracers (^{14}C, ^{39}Ar, ^{129}I, ^{236}U)

We will collect water samples from Niskin bottles that are attached to a Conductivity-Temperature-Depth (CTD) rosette to full depth. The first priority will be to sample stations that have been sampled in 2015. Samples will be taken at similar depths to 2015. Samples for ^{129}I and ^{236}U will focus on the upper 1,500 – 2,000 m. Samples for ^{39}Ar and ^{14}C will be collected at higher resolution in intermediate and bottom waters (from 1,500 down to 5,000 m).

We will take about 3 L water samples for the analysis of ^{236}U and ^{129}I in plastic cubitainers. Water samples for ^{39}Ar are collected in 12 L propane bottles that have been filled with nitrogen gas beforehand to avoid contamination with atmospheric argon. ^{14}C samples will be collected in 120 ml glass containers that are sealed air-tight right after the sampling process. The ^{14}C-samples are preserved on board with mercury chloride ($HgCl_2$) after sampling to avoid organismic modifications to the ^{14}C-content. All the samples will be further processed at ETH Zürich.

Preliminary (expected) results

Aerosol trace metals and major ions

Sample analysis will be done using methods applied to several other GEOTRACES cruises (e.g. Chance et al., 2015; Baker et al., 2020). This will allow us to estimate the contributions of different aerosol sources (e.g. combustion, mineral dust) to the atmospheric nutrient input to the Eastern Arctic Ocean, and (together with air mass trajectory analysis) to examine the spatial distribution of these sources. Detailed chemical analysis will also provide information on the factors that control micronutrient solubility and hence influence bioavailable nutrient supply.

Nutrient addition bioassay experiments

We expect that the Eastern and Central Arctic Ocean surface waters hosts two contrasting nutrient regimes in late summer: a.) Fe-replete, but fixed N-scarce conditions in surface waters of the Central Arctic Ocean Transpolar Drift, with low initial biomass owing to light limitation, and b.) Fe-scarce conditions, with a standing stock of fixed N and comparatively elevated phytoplankton concentrations in surface waters of the Eastern Arctic Ocean Nansen Basin. We expect that the interplay between Transpolar Drift and Atlantic Waters has a profound impact on late summer primary production in the region.

Dissolved and particulate trace metals (Fe, Mn, Co, Ni, Cu, Zn, Cd)

We expect comparatively low concentrations of dissolved and particulate trace metals in the Eastern Arctic Ocean compared to the Central Arctic Ocean which is under the influence from surface offshore advection of shelf-derived material with the Transpolar Drift. Concentrations of dissolved micronutrients are expected to increase with depth in the Eastern Arctic Ocean due to phytoplankton uptake in surface waters and remineralisation at depth. Conversely, we anticipate dissolved micronutrient concentration to be considerably lower than surface concentrations in the water column beneath the Transpolar Drift.

We expect dissolved micronutrient transport with the Transpolar Drift to have increased between 2007, 2015 and 2024 owing to increased fluxes of shelf-derived material across the East Siberian Shelf break. Yet, the decline in Central Arctic Ocean sea-ice cover may have resulted in increasing destabilisation of the underlying dissolved micronutrient-enriched Polar Surface Water and a less efficient micronutrient transport towards Fram Strait. We expect that Arctic Ocean surface primary production is increasingly depended on mixing between dFe-replete waters of the Transpolar Drift, and macronutrients (i.e. fixed N) supplied by Atlantic Water.

Dissolved Fe isotopic composition (δ^{56}dFe)

We expect changes in the relative importance of different iron sources along a south-to-north gradient between surface waters influenced by Atlantic Water (Eastern Arctic Ocean) and those influenced by the pronounced offshore transport of dFe with the Transpolar Drift. We expect the flow path of the Transpolar Drift low salinity waters to be characterised by near-crustal δ^{56}Fe signature as has previously been observed (around +0.1‰, but “ranging from −0.4‰ to +0.5‰” (Charette et al., 2020)). Regions and water layers of elevated primary production such as the Nansen Basin and the Barents Sea shelf break may show a heavy residual δ^{56}dFe, owing to preferential uptake of light Fe-isotopes by phytoplankton (Fitzsimmons & Conway, 2023). Vice versa, remineralisation of organic matter at depth or in sediments is expected to result in a low δ^{56}dFe pool. Dissolved Fe in the deep waters of the Eurasian Basin (> 1,200 m depth) is likely sourced from offshore advection of shelf material (Rutgers van der Loeff et al., 2018), likely with an isotopically light to crustal signature, with the effect of reversible scavenging with sinking particles modifying δ^{56}dFe (Fitzsimmons et al., 2017). More locally, the deep Arctic Ocean basin will also receive dFe inputs from hydrothermal sources (Klunder et al., 2012) which may be characterised by low δ^{56}dFe in the case of high-temperature hydrothermal fluid venting (Fitzsimmons & Conway, 2023).

Rare earth element concentrations and neodymium isotopes

Deep samples (> 1,500 m water depth) from reoccupied stations of cruise PS94 will be used for quality control since the deep water column is not expected to have changed in REE and Nd isotope compositions.

Gallium

There are no fixed expectations yet how strong the trend in data compared to previous results will be.

Mercury

We expect to measure higher concentrations of total Hg and MeHg due to the increased mean temperature during the summer, the decrease in MYI, and possibly higher inputs from rivers and thawing permafrost. We expect to observe and quantify the vertical transport of MMHg methylated at the bottom of the AO to the lower levels of marine trophic chains, namely phyto- and zooplankton. Combining the data from 2007, 2015, and 2024, we expect to have robust evidence of the possible temporal evolution of the Arctic Ocean Hg reservoir.

Natural radionuclides (^{230}Th, ^{231}Pa, ^{232}Th, ^{226}Ra, ^{228}Ra)

For ^{231}Pa and ^{230}Th, we expect to produce full water depth profiles from stations that were previously occupied during GEOTRACES, in order to assess temporal variability, e.g. trends in particle flux and advection due to changing climate, or at sites where previously hydrothermal removal aspects were seen. For ^{226}Ra, we expect to produce one or more sections with the best possible precision, in order to see scavenging effects and possibly release from slopes. ^{228}Ra/^{226}Ra will be sampled in surface waters to see if the trends that were previously observed and attributed to enhanced release from warming shelves continue. This is part of the international ARION partnership (AWI/ WHOI/ 1st Institute of Oceanography China). Ba will be assessed in context with previous analyses of freshwater systems. In total, we expect to cover possible changes in a broad range of sources to Arctic biogeochemistry, in line with the Arcwatch missions.

Dissolved Pb, particulate Pb (labile, refractory) and Pb isotopic composition

We expect dPb concentrations and fractions of anthropogenic vs. natural dPb in the Eastern Arctic Ocean to have declined between 2015 and 2024, owing to continuous scavenging of dPb from the water column (Cochran et al., 1990) in response to the phase-out of leaded gasoline and restriction to industrial emissions of Pb (Nriagu, 1990; Pacyna et al., 2009). During the same time interval, dPb concentrations in the Central Arctic Ocean may have increased, related to increased freshwater discharge to the East Siberian Shelf (Feng et al., 2021), enriched in natural Pb (Guay et al., 2010), and transport with the Transpolar Drift (Charette et al., 2020). We anticipate that Pb with anthropogenic signature has penetrated into deep waters of the Eurasian basins (> 1,500 m). Primary production and (reversible) scavenging with/on sinking particles, particularly along the Arctic Ocean boundaries, are major factors in Pb export and burial at depth.

Transient Tracers (^{14}C, ^{39}Ar, ^{129}I, ^{236}U)

There are no fixed expectations yet regarding the distribution of artificial radionuclides.

Data Management

Aerosol trace metals and major ions

The samples will be analysed by Alex Baker at the University of East Anglia. Quality control will be achieved through analysis of liquid- and solid phase certified reference materials. Results will be submitted to the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

Nutrient addition bioassay experiments

The results will be published on the PANGAEA Database and submitted to the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

Dissolved and particulate trace metals (Fe, Mn, Co, Ni, Cu, Zn, Cd)

The samples will be analysed at GEOMAR. Quality control will be achieved through intercalibration from triplicate samples at two stations which were occupied in 2015. Analytical runs are validated through the analysis of reference materials. The GEOTRACES Standards and Intercalibrations Committee will be asked for evaluation and approval. Results will be made available to the public within 2 years after the expedition.

The results will be published on the PANGAEA Database and submitted to the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

Dissolved Fe isotopic composition (δ^{56}dFe)

Dissolved Fe isotope ratios will be measured at Tampa Bay Plasma Facility at the University of South Florida following well-established chemical processing methods via multi-collector ICPMS (Conway et al., 2013). The samples will be analysed by Stephan Krisch and Tim M. Conway within two years after completion of the expedition. The data will be submitted to Pangaea and the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

Rare earth element concentrations and neodymium isotopes

These results will be submitted to the GEOTRACES Intercalibration and Standards Committee for evaluation and approval. All data and metadata will be submitted to Pangaea and the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

Gallium

Deep samples (> 1,500 m water depth) from reoccupied stations of cruise PS94 will be used for quality control since the deep-water column is not expected to have changed in Ga concentrations. These results will be submitted to the GEOTRACES Intercalibration and Standards Committee for evaluation and approval. All data and metadata will be submitted to the Arctic Data Center and the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

Mercury

Reference materials will be used to validate all analytical runs through analysis. Quality control measures will include intercalibration with triplicate samples from two stations that were also targeted in 2015. The evaluation and approval of the GEOTRACES Standards and Intercalibrations Committee will be sought. The results will be available to the public within a two-year time frame after the expedition. The PANGAEA Database will be the primary repository for the obtained results, submitted to the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme (http://www.geotraces.org).

Natural radionuclides (^{230}Th, ^{231}Pa, ^{232}Th, ^{226}Ra, ^{228}Ra)

Data acquired will be part of the international GEOTRACES programme, which has a dedicated data management plan, including standardized quality management, standardized variables and units, data curation, a database hosted at the British Oceanography Data Centre, and defined open data/accessibility plans.

Dissolved Pb, particulate Pb (labile, refractory) and Pb isotopic composition

Quality control will be achieved through intercalibration from triplicate samples at two stations which were occupied in 2015. The GEOTRACES Standards and Intercalibrations Committee will be asked for evaluation and approval. The samples for dPb, labile particulate and refractory Pb will be analysed by Yaqing Ruan at GEOMAR. Measurements of isotopic composition of dPb and particulate Pb will be conducted by Mengli Chen and Xianfeng Wang in Singapore. Results will be made available to the public within 2 years after the expedition. The results will be published on the PANGAEA Database and submitted to the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

Transient Tracers (^{14}C, ^{39}Ar, ^{129}I, ^{236}U)

The results will be published on the MARIS Database and submitted to the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

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.

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In all publications based on this expedition, the **Grant No. AWI_ PS144_01** will be quoted and the following publication will be cited:

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3. IMPACT OF ICE DRIFT ON NUTRIENT AND TRACE-METAL DISTRIBUTION, OCEAN PRODUCTIVITY AND CARBON EXPORT (BIOLOGICAL TRACE METALS – BTM)

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Objectives

Arctic phytoplankton is known to be limited primarily by nitrogen availability (Ko et al., 2020). However, investigations of potential co-limiting factors, such as iron, remain limited. While research indicates that ice originating from the Siberian shelves and transported via the Transpolar Drift serves as a primary source of nutrients and trace metals to the central Arctic (Charette et al., 2020), the precise contribution of these ice-derived elements to Arctic Ocean productivity and carbon sequestration, and the implications of different ice types remain uncertain. Additionally, global warming foresees increased ice-melt and freshwater inputs to the Arctic Ocean, potentially reshaping seawater biogeochemistry, thereby affecting primary productivity, phytoplankton community structure, and CO_2 export to the depth (Krumpen et al., 2019). The predicted increased Arctic stratification due to global warming may further disrupt nutrients and trace metal upwelling, potentially increasing the significance of nutrients and trace metals released from melting sea ice (Krisch et al., 2020). Augmented primary production resulting from ice melt could alter the biological carbon pump and the Arctic carbon sink, a critical consideration within the broader context of climate change.

We aim to identify potential nutrient limitations of Arctic phytoplankton and investigate the impact of the release of trace metals, particularly iron and macronutrients from melting sea ice, on CO_2 fixation by Arctic phytoplankton and its export to depth. For this, we will conduct *in-situ* measurements to characterize the biogeochemical setting of surface water (10 m sampling depth) and, at some sites, also of the chlorophyll maximum. The carbon export will be estimated by measuring the natural radioisotope thorium-234 along the water column (Roca-Martí et al., 2016). In addition, we will drill ice cores using trace metal clean techniques to characterize the bottom sea ice and under ice water. Furthermore, we will conduct ice-addition phytoplankton incubation and aggregation studies.

As part of the overall goal of PS144, we aim to:

- Estimate trace metal quotas, ^{14}C primary production, single-cell trace metal mapping, and photophysiology in surface water and/or at the chlorophyll maximum, as well as in the bottom sea ice and under ice water.
- Identify community composition via light microscopy, flow cytometry, and metagenomics in surface water and/or at the chlorophyll maximum as well as in the bottom sea ice and under ice water.

- Determine the carbon export from the surface to deeper waters (8 depths) using thorium-234.
- Conduct four bottle incubation experiments for 5-10 days to assess the impact of ice-associated trace elements (particularly iron) and nutrients on the Arctic phytoplankton production and species composition. After 5-10 days, incubate the final phytoplankton communities for 1-2 days in roller tanks to promote aggregate formation and asses ice-induced changes in the carbon content and export potential of the newly formed aggregates.
- Link the in situ and carbon export data and the aggregation data from the incubation experiments to evaluate the potential importance of ice-mediated nutrient and trace element input.

Work at sea

To characterize the *in-situ* conditions (^{14}C primary production, intracellular macronutrient and trace metal distribution, trace metal quotas, photophysiology, metagenomics, and community composition), seawater will be sampled at 30 stations at the surface (10 m depth) and/or the chlorophyll maximum using a trace metal-clean Teflon CTD rosette. Depth profiles will be taken at approximately 30 stations to assess the carbon export.

Additionally, at five ice stations, the bottom ice will be trace metal clean sampled with a Kovac ice corer of 9 cm diameter, and the ice underwater will be sampled with a clean water pump. These samples (bottom ice and ice underwater) will be analysed for trace metal contents (Fe, Mn, Co, Cu, and Zn), primary production, intracellular macronutrient and trace metal distribution, photophysiology, metagenomics, and community composition. In cooperation with Sinhué Torre's and Hauke Flores' teams, information on macronutrients and POC concentrations will be obtained. For the incubation experiments, we will also sample bottom ice from all ice stations for the ice-addition incubation experiments. At four potential FeN co-limited sites, we will sample ~100 L surface water using the trace metal clean Teflon CTD rosette.

More specifically:

1. At ~30 stations, seawater will be collected with AWI's new, state-of-the-art, trace metal clean sampling infrastructure, including a Teflon CTD equipped with OTE bottles (12L/bottle capacity) and winch. Water will be sampled at the surface and/or the chlorophyll maximum. Onboard, macronutrients will be analysed by Sinhué Torres. Fe concentrations of the sampled bottom sea ice will be analysed by flow injection (FIA) with luminol chemiluminescence detection. Primary production rates will be determined using 14Cbicarbonate. Using a Fast Repetition Rate fluorometer (FRRf), we will assess the photophysiological status of the sampled phytoplankton community. In addition, samples will be taken to determine the intracellular content of trace metals (Fe, Mn, Zn, Co, and Cu) of the phytoplankton community. In addition, we will take samples, which will enable us to estimate the intracellular trace metal distribution of single cells. Samples will also be collected to determine the community composition via light microscopy and flow cytometry. Also, metagenomic samples will be collected, which will provide information on species composition, but also on functional changes of metabolic pathways of the microbial community.
2. At ~30 stations, seawater will be sampled using a regular CTD rosette at eight depths to assess the thorium-234 content onboard. This information will afterwards be combined with POC analyses on the same filters and combined with 234Th to calculate the carbon export from the ocean surface.

3. At five ice stations, the bottom ice will be trace metal-clean sampled with a Kovacs ice corer of 9 cm diameter, and the ice underwater will be trace metal-clean sampled with a water pump. Samples will be analysed for macronutrients, trace metal quotas, POC, primary production, single-cell nutrient stoichiometry, taxonomy, metagenomics, and photophysiology, as described before. Additional ice cores will be taken at each ice station for ice-addition phytoplankton incubation experiments. The goal is, therefore, to obtain ice material from different origins and with different chemical compositions, e.g., ice containing terrigenous material and marine sea ice with no terrigenous input. Sea ice back-tracking, performed by Thomas Krumpen, will allow us to determine the ice sources.

4. At four sampling stations (20 m), one ultra-clean CTD cast will be required to sample seawater with the local phytoplankton community for bottle incubation experiments. Treatments will include adding melted and 0.2 µm filtered sea ice from different sources (terrestrial and marine), nitrate (+N), iron (+Fe), and nitrate and iron combined (+FeN). All bottles will be incubated in climate-controlled laboratories. The incubations will last 5-10 days, and macronutrient concentrations will be determined every second/third day by Sinhué Torres to follow macronutrient drawdown as an indirect indicator for phytoplankton growth. Also, the photophysiological status of the cells will be regularly determined. Concentrations of iron, macronutrients and POC, primary production, single-cell nutrient stoichiometry, photophysiology, metagenomics, and community composition will be assessed at the start and end of the experiment. In the next step, 1.2 L of the final community of each treatment will be incubated in the dark in roller tanks to avoid further phytoplankton growth and to promote aggregate formation. Sinking velocity, particle abundance, and size will be monitored by video analysis. Finally, the aggregates will be picked and sampled to determine the POC content of the aggregates and the background seawater. Additionally, one roller tank will be spiked with thorium-234 to investigate its time-related absorption on the particles.

Preliminary (expected) results

The expected data set will characterize the Arctic phytoplankton community, primary production, carbon export, and trace and macronutrient concentrations in the central Arctic. We will identify potential nutrient limitations of Arctic phytoplankton and elucidate the impact of ice-associated nutrients on CO_2 fixation by Arctic phytoplankton. Linking the *in situ* and carbon export data to changes in sea-ice formation and transport will allow us to evaluate the potential importance of ice-mediated nutrient and trace element input for the future Arctic Ocean.

In addition, targeted experiments in which natural plankton communities are spiked with melted sea ice from various sources will determine the fertilization effect of melted sea ice by releasing trace elements and nutrients to phytoplankton. Additional treatments will assess the single (+N and +Fe) and combined effects of nitrate and iron (+FeN) to determine potential nutrient co-limitations. The data generated by the aggregation experiments will reveal the impact of ice-associated elements on the carbon export flux in the central Arctic. Moreover, the thorium spike experiment will elucidate time-related thorium scavenging on different-sized particles.

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 (www.pangaea.de) within two years of the end of the cruise. 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 EMBL-EBI/ENA, GenBank, and DDBJ). Environmental proteome data will be deposited in the publicly accessible Ocean Protein Portal (https://proteinportal.whoi.edu).

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.

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In all publications based on this expedition, the **Grant No. AWI_** PS144_02 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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4. PHYSICAL OCEANOGRAPHY – PO

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Outline

The observational programme of the Physical Oceanography (PO) Team includes research from the AWI and the University of Gothenburg, and under the secondary user proposals A2A (University of Bremen, Germany), IPA-ArcWatch 2 (Sun Yat Sen University, Taiwan) and DTOP-AW2/TA3 (Ocean University of China, China).

Objectives

The central Arctic Ocean is a crucial part of the global climate system, yet it is notoriously under-observed. Decades of repeat surveys using icebreakers and autonomous instrumentation and, to some extent, remote sensing, have allowed for the identification of 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. Rabe et al. 2014), while water sample analysis has led to further insight into water mass pathways by using various tracers (e.g. Huhn et al. 2018).

Waters imported to the Arctic Ocean are subject to cooling, freezing and melting, altering the properties of these water masses (e.g. Rudels et al. 2021; Timmermans and Marshall 2020). The warm inflow of waters of Atlantic origin occurs via two pathways: the eastern Fram Strait and the Barents Sea. These two branches are subject to transformation by surface processes and lateral mixing before and after entering the Nansen Basin. Continental runoff enters the Eurasian and Makarov basins via the extensive shelf regions north of Eurasia, before advected within the Transpolar Drift and, at times, the Beaufort Gyre. In the central Arctic, stratification due to fresh water in the mixed layer and the halocline inhibits the release of heat from underlying waters to the atmosphere. This stratification is maintained by continental runoff, and ice or meltwater. However, changes may occur from the different wind mixing with and without ice cover, and the fact that now large areas have longer seasons without sea ice.

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-ICE2015 (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.

Besides, in the absence of sustained time series of observations in the Arctic, trace gases provide a unique tool to observe ventilation time scales and circulation changes by estimating tracer ages (e.g., Karcher et al. 2012; Smith et al. 2021, 2022). During the MOSAiC expedition, we acquired a data set of anthropogenic trace gases and noble gas isotopes (Rabe et al., 2022; Heuzé et al. 2023) of the upper ocean along the drift track. This data set offers a unique opportunity to study a diverse set of processes, for example water mass ventilation (Huhn et al. 2013), ice melt (Huhn et al. 2018; Rhein et al. 2018), air-sea gas exchange (Wanninkhof et al. 2004), upwelling (Jenkins 2020), or dispersal of hydrothermal input (German et al. 2022) that affect concentrations and isotopic ratios. However, the new data set has the inherent problem that the observations during the MOSAiC drift show a mixed temporal-spatial signal. Especially for the upper ocean and mixed layer, seasonal and regional variability are difficult to disentangle. During PS144 we will complement the MOSAiC winter data with a data set from the same region, but during summer, which will facilitate to identify individual processes. Additionally, we will extend the vertical scope of the sampling towards the deep water (that is not affected by seasonal variability) to study the age distribution, renewal times and the role of slope convection of the deep water masses of the Arctic Ocean.

The team aims to improve the temporal and spatial oceanographic data coverage on the basin scale in the Eurasian and Makarov basins, as well as to use the ice station time to study local processes, such as leads, shallow ocean stratification, turbulence, and feedback with the ice, snow and atmosphere system. Several hydrographic sections will improve our understanding of changes in time by repeating work from earlier cruises the have been conducted since the early 1990s with the icebreakers *Polarstern* and *Oden*, and within the NABOS (Nansen-Amundsen Basin Observation System) project. These observations will be augmented by upper-water-column hydrography perpendicular to the sections to capture horizontal gradients in all directions. We will run continuous and on-station measurements of current velocity to aid the interpretation of the hydrographic data and estimate transports. To extend the observational range of the ship survey in space and time, we plan to deploy autonomous, ice-based buoys, and deploy and recover bottom-moored observatories. From the sea ice, we will use a turbulence profiler to obtain estimates of fine structure and turbulent energy dissipation in the upper water column. This will improve our understanding of vertical mixing processes in the context of large-scale hydrography. 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 especially GEOTRACES (e.g. Charette et al. 2020).

Work at sea

As part of the physical oceanography work program, we will measure a variety of seawater properties along the cruise track using different sampling methods, platforms, and sensors both from the ship and from the sea ice. In addition, we will deploy a suite of ice-based buoys, ARGO floats, and a large number of eXpendable CTDs to extend these measurements in time and space, and to support a variety of international programs in their efforts to collect rare atmosphere, sea ice and ocean data in the central Arctic.

Ship-based hydrographic work programme

The ship-based Conductivity Temperature Depth system mounted on a rosette with 24 x 12l Niskin bottles 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 and photosynthetically active radiation **(PAR)**. Surface PAR (**SPAR**) will be recorded in parallel. Additionally, a Lowered Acoustic Doppler Current Profiler (**LADCP**), an underwater vision profiler (**UVP**), and a **SUNA** nitrate sensor will be mounted on the frame to collect data autonomously. This CTD will be used in conjunction with an ultra-clean CTD/ rosette system, operated by the Biological Trace Metal (BTM) team.

Water samples will be collected for various parameters as well as for in-situ calibration of sensor data. CTD-casts will be utilized for cross validation of data recorded with other types of CTDs such as Sea&Sun or RBR. For comparison, those instruments will be mounted to the CTD/Rosette for selected casts.

We intend to obtain about 500 water samples for CFC-12 and SF_6, about 400 water samples for noble gas isotopes He isotopes and Ne, and 150 water samples for tritium from the ship deployed full depth profiling CTD and water sample system.

Water samples for CFC-12 and SF_6 measurements will be stored from the ship deployed water samplers into 200 ml glass ampoules and will be sealed off after a CFC and SF_6 free headspace of pure nitrogen has been applied. The samples will be analyzed post-cruise in the CFC and SF_6 laboratory at the IUP Bremen. The determination of CFC-12 and SF_6 concentrations is accomplished by purge and trap sample pre-treatment followed by gas chromatographic (GC) separation on a capillary column and electron capture detection (ECD). The amount of CFC-12 and SF_6 degassing into the headspace is accounted for during the measurement procedure in the lab. The system is calibrated by analyzing several different volumes of a known standard gas. Additionally, the blank of the system are analyzed regularly. For details see Bulsiewicz et al. 1998.

The oceanic water samples for helium isotopes and neon will be stored from the CTD and water bottle system into 50 ml gas tight copper tubes, which will be clamped of at both sides. The noble gas samples are to be analyzed post-cruise in the IUP Bremen noble gas mass spectrometry lab. The copper tube water samples will be processed in a first step with an ultra high vacuum gas extraction system. Sample gases are transferred via water vapor into a glass ampoule kept at liquid nitrogen temperature. For analysis of the noble gas isotopes the glass ampoules are connected to an ultra-high vacuum mass spectrometric system equipped with a two-stage cryogenic trap system. The system is regularly calibrated with atmospheric air standards. Also measurement of blanks and linearity are done. For details see Sültenfuß et al. (2009).

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 transit through ice but also along the main hydrographic transects, up to 120 **eXpendable CTDs (XCTD)** (model: XCTD-1 from TSK, up to 1000 m depth) will be launched to improve the horizontal resolution of the measurements to the order of ~15 – 20 km. If time and weather allow, helicopter-based measurements will also be carried out perpendicular to the cruise track using a light-weight, self-recording CTD sensor package operated on a **motorised fishing rod**. These data can yield regional differences of the internal wave field from the Barents Sea toward the Makarov Basin. The two prominent bathymetric features, Gakkel ridge and Lomonosov Ridge, should play a role reflecting deep internal wave energy upward to the sea surface. This hypothesis is yet to be investigated to our best knowledge. These hydrographic observations will be collected alongside with subsurface underway velocity measurements by the **ship-based 150kHz Acoustic Doppler Current Profiler (SADCP).** Additionally, a duplicate thermosalinograph (TSG) will continuously be recording surface temperature and salinity along the cruise track.

Ice-based work

During **ice stations**, a generator-powered **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 in the upper 400m. We will deploy a **300kHZ ADCP** in conjunction with the MSS measurements to record ocean currents in the upper ocean, and opportunistically use additional salinity and temperature recorders, as well as additional ADCPs.

One focus of our on-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. For example, we will use a **modified CTD in upward profiling mode** to determine the thickness of the meltwater layer, if present. Another focus is on the dynamics and fluxes in the ice-ocean boundary layer. 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 a **high-resolving ADCP** (Nortek Signature 1000) we aim to obtain direct observations of the fluxes. Depending on the available time, we plan to subsequently deploy this instrument in different locations on the same floe to determine the effect of under-ice topography, especially ridge keels, and drift speed on under-ice turbulence. Under favourable conditions, we plan to use a small boat to record turbulence profiles in leads using **self-recording microstructure profilers**.

Oceanographic buoy deployments

We will set up a network of autonomous, ice-tethered buoys across the central Arctic pack ice region in order to record sustained distributed measurements of the atmosphere-ice-ocean system until long after the expedition concludes. These efforts contribute to various international programs and Arctic monitoring activities. We will deploy 3 **Ice-Tethered Profilers** (ITPs) in collaboration with WHOI, 2-3 **profiling IAOOS systems** in collaboration with LOCEAN, and 2 **CTD chain buoys** on a number of ice stations upstream in the Transpolar Drift to record profiles of various upper ocean properties. Additionally, three **drift-towing ocean profilers (DTOP)** will be deployed, which consists of four components: surface package, cable, CTD profiler and ice chain. The meteorological sensors mounted on the surface package provides **air temperature**, **relative humidity** and **sea level pressure** by 1 hour, and the CTD profiler is deployed through the ice hole into the ocean to measure **temperature** and **salinity** with a sampling frequency of 12 hours. Ideally, the vertical range of profile is from 0.2m beneath the ice bottom to the maximum depth DTOP can reach, depending on the length of cable (2x 125m and 1x 200m in PS144) and the velocity. Additionally, an ice chain is attached on the surface package to obtain the **temperature inside the sea ice**. These ocean-focused activities will be complemented by a number of meteorological and sea ice buoys that will be installed on the same ice floes, or deployed during short stops using the mummy chair or helicopter. Details can be found in the respective chapters.

Other work

Two **ARGO floats** will be deployed in the Nansen Basin near Svalbard and in the eastern Amundsen Basin to obtain profiles in these regions beyond the duration of the expedition, and to further improve the use of this technology in the (partly) ice-covered Arctic Ocean. This activity is supported by the German Hydrographic Institute (BSH).

We will **recover two seafloor-mounted moorings** co-deployed in the eastern Amundsen Basin during PS138. One is a physical oceanography mooring that is equipped with a newly-developed, 25 m long pipe segment at the top to reach a depth as shallow as 10 m. This mooring is equipped with a large number of CTDs and temperature loggers, as well as 2 ADCPs and a Sonovault sound recorder. The second mooring deployed close-by includes two Remote Access Samplers (RAS) also equipped with sensors sets for nitrate, pH, pCO2, and CTD-DO, and additional PAR and EcoTriplet sensors on the upper RAS. The mooring further includes two sediment traps, an Acoustic Zooplankton Fish Profiler, another Sonovault, an ADCP and a number of CTDs and current meters. If the recovery will be successful, we plan to **re-deploy one mooring** at the same location, equipped with a 25 m long tube segment at the top and a large number of salinity and temperature recorders distributed within the upper 300 m.

Preliminary (expected) results

We expect to obtain near-real time locations and meteorological data once per hour and hydrological data every 12 hours, which will be processed until all devices become offline. We expect to have *in situ* sensor data, accompanied by tracer measurements, processed a few months after the expedition. Some of the tracer data may be processed later than the sensor data, depending on laboratory time being available on land. Data from sensors and from RAS samples will be available approximately 6 months after mooring recovery in 2025.

Overall, we will continue the central Arctic long-term observations and time series of fresh water and other inventory quantities. We expect to elucidate stratification and vertical fluxes associated with leads, sea ice melt and formation, and surface momentum flux. Further, we will get further insight into the large-scale state of the Eurasian Basin about 1 year after PS138, 4 years after MOSAiC, and 9 years after PS94. With the tracer observations proposed here, we aim to contribute to the following specific questions: (I) What is the water age distribution in the different layers / water masses? Are the observed ages compatible with existing circulations schemes for the Atlantic water and the deep water? (II) What is the role of slope convection for the ventilation of the deep Arctic Ocean, and are there recent changes? (III) What is the role of seasonal versus spatial variability in upper ocean processes in the central Arctic with regard to the observations carried out during MOSAiC?

Data management

Environmental data will be archived, published and disseminated according to the FAIR principles at 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 by default. These data are also fed into the database of the International Arctic Buoy Programme IABP at https://iabp.apl.uw.edu/index.html, and will be made available in near-real time on www.meereisportal.de. Selected buoys also report their data directly to the WMO's Global Telecommunication System (GTS), thereby contributing to improved global numerical weather predictions. Buoy data will also be made available on PANGAEA within two years after a buoy ceased operation.

This part of the 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. Trace gas observations are supported by the DFG CRC 172 (AC)3 - Arctic Amplification.

In all publications based on this expedition, the Grant No. AWI_ PS144_03 will be quoted and the following publication will be cited:

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5. NUTRIENT BIOGEOCHEMISTRY, NITROGEN ISOTOPISM DISSOLVED ORGANIC MATTER (DOM) AND WATER ISOTOPES (MARINE BIOGEOCHEMISTRY – MBC)

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Outline

The observational programme of the Marine Biogeochemistry (MBC) Team includes research from the AWI, University of Edinburg and by Texas A&M University, Christian-Albrechts-Universität zu Kiel and GEOMAR, under the secondary user proposal DOMAHAWK.

Objectives

Nutrient biogeochemistry: Under a rapid changing Arctic Ocean, monitoring key processes over long time scales is important to determine how changes in ocean dynamics affect biogeochemical cycles and ocean productivity. Atlantic Water entering via Fram Strait and the Barents Sea Opening supply nutrients to the Nansen and Amundsen basins, contributing to the Arctic Ocean nutrient budget providing rich nutrient waters at depth. With current changes in sea ice decline, the resulting stratification and changes in the Atlantic Water inflow it is important investigate how these may impact nutrient supply to the Arctic Ocean sunlit layers and how the interaction between physical and biological processes modify nutrients along the pathway of Atlantic Water, which will eventually be reflected in the wider nutrient budget. Our global aim is therefore to measure nutrient fields during PS144 in order to assess them in relation to previous observations within the context of ArcWatch objectives (i.e., long term observations). Additionally, we aim to investigate nutrient relative abundance in the central Arctic Ocean in relation to horizontal nutrient supply in Fram Strait and determine how this impacts the Arctic Ocean nutrient budget.

Nitrogen isotopes: Primary productivity in the Arctic Ocean appears to be limited by the availability of nitrogen (Yamamoto-Kawai et al., 2006). Biologically available nitrogen is lost in the Arctic Ocean through shelf productivity (i.e., phytoplankton uptake and sediment burial) and sediment denitrification. Denitrification in shelf sediments, such as that occurring off Siberia, leads to significant N losses in the upper water column of the Arctic Ocean (Yamamoto-Kawai et al., 2006). This process is thought to be responsible for the N limitation in the Arctic Ocean. Denitrification is particularly sensitive to shelf processes such as changes in shelf productivity, circulation, and diapycnal mixing, which result from the reduced sea-ice cover (Codispoti et al., 2013). Primary productivity along the shelf edge bordering the Siberian shelves has increased by 96-117% over the last two decades (Lewis et al., 2020) which in turn should have driven an increase in denitrification rates as these processes are proportional (Chang and Devol, 2009). This is expected to have biogeochemical implications at a pan-Arctic scale as the shelves are connected to the Fram Strait outflow gateway via the Transpolar Drift (Debyser et al., 2022). It is postulated that the balance between N inputs and outputs which was in delicate balance (Torres-Valdés et al., 2013) might have transitioned to an N deficit. This work aims to quantify this N loss in the Transpolar Drift through the use of stable isotopes and inverse modelling.

The main objective is to understand the role of various N cycling processes in determining loss of nitrate in the N-limited Arctic Ocean. To this end, we will disentangle the influences of biogeochemical processes, horizontal transport and vertical mixing in the chemical and isotopic compositions of waters in the upper water column in the central Arctic which are under the influence of the Transpolar Drift. These processes will be evaluated from an analysis of measurements of nitrate concentrations and isotopic measurements and from the development and application of mathematical models describing the cycling of nitrogen in the upper Arctic.

Dual isotope signatures of $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$ allow tracing nitrogen cycling processes as they exhibit characteristic isotopic fractionation trends (Sigman and Casciotti, 2001). Quantification of N cycling processes along the Transpolar Drift would allow untangling the N deficit signal associated with shelf denitrification. This is possible as, during denitrification, the $^{15}N/^{14}N$ ratio of nitrate tends to increase due to the preferential uptake of the light isotope by denitrifying bacteria, leaving the residual nitrate enriched in the heavy isotope, while $^{18}O/^{16}O$ decreases due to isotopic exchange with ambient seawater (Fripiat et al., 2018).

Our first aim is to compare nutrient stoichiometry and N isotope values we obtain from this cruise with previous measurements (TransARC II, 2015; MOSAiC, 2019/20; ArcWatch I, 2023) to see if there are discernible changes in N cycling/deficit. Our second aim is to improve the coverage of isotopic data in the central Arctic Ocean to a density that will allow us to use inverse methods to address present and future changes in N cycling and N availability.

The dataset collected will be interpreted in the context of a wide range of oceanographic and biogeochemical data collected during the cruise. Specific questions to be addressed are:

1. What is the magnitude of various sources and sinks of N in the central Arctic Ocean and how are they changing (including shelf denitrification N losses)?
2. How are these changes impacting nitrate levels in various Arctic water masses?
3. Ultimately, what are the likely consequences of current climate change on the future Arctic Ocean N budget and productivity?

DOMAHAWK: The overall purpose of the project is to further understand the effects of sea-ice processes on the water mass structure of the central Arctic Ocean halocline in order to get a basis to estimate future and ongoing effects of climate changes on the distribution and transport of constituents such as of carbon, nutrients and trace elements (TE) within the upper water column of the Transpolar Drift (TPD). The wind-driven TPD in the central Arctic Ocean is the main transport pathway connecting the Siberian shelves to Fram Strait and enabling the transfer of Siberian river water and constituents to the North Atlantic. However, a comprehensive understanding of the actual influence of the TPD remains elusive, particularly due to the complex seasonal ice-ocean interactions. Recent studies (Slagter et al. 2017, 2019; Charette et al. 2020, Williford et al. 2021, 2022) in the Arctic Ocean suggest the transport, distribution and fate of DOM, water isotopes and TE are closely intertwined, and the ArcWatch2 programme provides an unique opportunity to further explore the interactions between DOM, water isotopes and TE. The proposed research builds and expands on our previous research on the origins, transformations and fate of DOM in the Arctic and will provide an unprecedented comparison of DOM and TE biogeochemistry in large parts of the central Arctic Ocean. We propose a suite of chemical and optical characterizations of DOM that will distinguish terrigenous and marine DOM as well as its bioavailability and extent of diagenetic alteration. In order to address the role of DOM for the distribution and cycling of TE, and to understand potential changes due to increasing freshwater discharge and receding summer sea-ice cover, we have the following goals, objectives.

1. To assist and provide the international Arctic Geotraces community with data on water isotopes (δ18O) and on the abundance, distribution, origin and composition of dissolved organic matter in the central Arctic Ocean.
2. To understand the effects of increasing continental runoff and declining sea ice on carbon and trace element cycling and hydrography of the central upper Arctic Ocean.

Work at sea

1. We will collect seawater samples from CTD-Rosette casts at all hydrograpic stations, for the measurement of dissolved nutrients (nitrate+nitrite, nitrite, phosphate, silicate, ammonium, total dissolved nitrogen and total dissolved phosphorus) and dissolved oxygen. We aim to carry our the measuremtns onboard.
2. We will recover two biogeochemical packages consisting of remote access samplers equipped with sensors (pH, pCO2, SUNA-Nitrate, PAR, EcoTriplet, CTD-O2) that were deployed in the central Arctic Ocean during PS138.
3. We will collect water samples from CTD-Rosette casts for N and O isotope analysis of nitrate. Their analysis will be carried out after the expedition at the Wolfson's Mass Spectrometry Laboratory at the School of GeoSciences, University of Edinburgh. Measurements will target areas where the Transpolar Drift flows and near the margins, and alternative stations elsewhere. Samples will be taken at all depths in the upper 300 m and alternative depths below. Broadly, our sample depths should coincide with depths where there is also nutrient analysis. Data will be combined with hydrological data (water mass identification), chemical data (nutrients, O2, d18O, CDOM), biological data (POC and PON concentrations and isotopes) and physical data (vertical diffusivities and advection) to derive estimates of N loss in the Transpolar Drift.
4. Water samples and *in situ* fluorescence data will be collected at approximately 60 hydrographic stations during PS144. We plan to collect water samples for the analyses of dissolved organic carbon (DOC), optical properties (absorbance and fluorescence), and total dissolved lignin phenols as well as oxygen isotopes (δ18O) of water. In addition, *in situ* fluorometers will be used at every station during the cruise. We plan to sample 16-24 depths at the regular CTD stations. More specifically for water isotopes, we plan to take water samples for stable oxygen isotope analysis (δ18O) in parallel to CTD measurements and hydro-chemical sampling. Sampling is planned within the halocline and the intermediate waters down to a depth of about 1,000 m. Sampling within the deep and bottom waters is planned for a sub-selection of stations. Sampling will be conducted along sections across the Transpolar Drift. Water sampling for δ18O analysis (50 ml) from CTD-rosette throughout the water column at all available rosette CTD stations and depth levels (but no multiple casts). With planned sampling depth levels at about: 10, 25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 500, 600, 800, and 1,000 m. At selected stations further sampling down to the sea floor at additional depth levels: 1,250, 1,500, 1,750, 2,000, 2,250, 2,500, 3,000 m, to bottom depth. We will collect 50 ml of water for each 18O sample from the CTD-Rosette. No water is needed for flushing. Since δ18O is measured on the oxygen of the H2O itself, it is not a trace-

element and its conservation is relatively easy. No poisoning of the water is necessary and some gas-exchange on a short time scale (e.g. bubbeling while sampling) is of no harm. For DOM we will collect 1,250 ml for DOC, optical properties and lignin phenols at 12 depths at most stations.

Preliminary (expected) results

All working well with the equipment onboard, we expect to have nutrient and dissolved oxygen fields a long the planned cruise transects by the end of the expedition.

We expect that horizontal advection from the Siberian shelves are essential to explain nutrient and isotopic distribution in the upper Central Arctic, specifically in Makarov and Amundsen basins. These basins are under the Transpolar Drift influence and are thus affected by riverine inputs and shelf denitrification occurring over the shelves. Despite increases in terrestrial inputs, we expect that riverine fixed N is predominantly lost on the shelves through denitrification and would have a limited role in alleviating N limitation in the upper Central Arctic.

Based on previous data (Amon et al. 2024) we expect to use the *in-situ* fluorescence data to track the distribution of river water and the halocline layers in the central Arctic Ocean. This signal will help guide sampling efforts for many groups on board. Based on *in situ* fluorescence we will select sampling depths for the other DOM parameters and for water isotopes. With the newly developed method for lignin phenols, a specific biomarker for terrigenous DOM, we will collect the first high resolution sample set, allowing to better constrain the distribution of river organics, halocline formation and freshwater source identification. In addition, the 2024 data set can be compared to previous efforts in 2005, 2007 and 2015 and allow to observe changes over the last 20 years.

For water isotopes specifically, samples will be transported to Kiel. Analysis will be conducted at the Leibniz Laboratory at Kiel University, Kiel, Germany and partly at the Stable Isotope Facility at CEOAS at Oregon State University, Oregon, USA. We will facilitate stable oxygen isotopes ($\delta^{18}O$) in a mass balance calculation together with salinity and hydro-chemical constituents to quantify freshwater fractions i.e. river water and sea-ice melt or formation. The water mass fractions will be compared to constituents such as carbon, nutrients and TE. This will allow to investigate the fate of e.g. the terrestrial carbon components but will also deliver additional information on the local freezing cycles. We hypothesize that during freezing events river water may be largely stripped of dissolved components. Comparison of expected versus observed concentrations of river derived constituent will allow to derive semi-quantitative information on refreezing effects. From previous investigations in the Central Arctic Ocean e.g. in summer 2007, 2015 and 2019/20 we know that there is spatial and temporal variation of freshwater distribution within the Arctic Ocean halocline on an interannual and seasonal timescale (Bauch et al., 2011; Paffrath et al., 2021; Bauch et al., in prep). Investigations within the TPD as covered by PS144 allow to capture (i) the transported signal from the Siberian shelves in which the local sea-ice modification of constituents is expected to be relatively low due to a relatively short mean residence time (Schlosser et al., 1994) and (ii) the gradient between the TPD towards the Canadian side in which local sea-ice modification of river derived constituents is expected to be relatively strong due to considerably longer mean residence times (Schlosser et al., 1994, Charette et al., 2020; Pasqualini, 2021). In addition, the project will estimate the rate of local versus advected sea-ice signal within different parts of the TPD.

The results will provide further understanding of the impact of sea-ice processes on the structure of the Arctic halocline and the TPD. Understanding sea-ice processes in the TPD has a wide impact as these precondition Arctic surface waters to become incorporated in North Atlantic Deep Water at downstream convection sites. DOM parameters will be determined at Texas A&M University.

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.

In situ fluorescence will be part of the CTD data set released by the physical oceanography group.

In addition, all DOM and $\delta^{18}O$ data and metadata will be submitted to the Arctic Data Center and the international GEOTRACES data management office (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org.

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.

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In all publications based on this expedition, the **Grant No. AWI_ PS144_04** 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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6. SEA-ICE PHYSICS – SIP

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Grant-No. AWI_PS144_05

Outline

The sea-ice physics programme is composed out of a standard sea-ice measuring programme and two secondary-use projects. Water vapor, properties of mixed-phase clouds, and microwave surface emissivities will be measured and analyzed as part of the secondary-use project Water Vapor, Mixed-Phase Clouds, and Sea Ice Emissivity over the Central Arctic Ocean (VAMPIRE). Dedicated Unmanned Aerial Vehicle (UAV) operations for ice navigation and for measuring sea ice related parameters will be carried out as part of the secondary-use project Drone and AI-based image solutions foR sciEnce and iCe navigaTion (DIRECT).

Objectives

By reflecting most of the incoming solar radiation sea ice keeps the Arctic Ocean cold and its decline has significant effects on the local and global climate. Therefore one of the main objectives during ArcWatch-2 is to closely monitor its characteristic parameters and to extend time series from previous expeditions. Furthermore new techniques such as UAV based laser scanning and melt pond depth retrievals will be tested. Also, *in-situ* measurements to improve satellite retrievals of water vapor content will be conducted and new tools and techniques for ice navigation will be evaluated under real conditions.

More specifically, our objectives can be sub-divided into three sub-topics, contributing to (i) an improved understanding of the sea ice, (ii) its interaction with the atmosphere and (iii) supporting new ideas for ice navigation.

Ice thickness and mass balance

Our goal is to study the ice thickness distribution on different spatial and temporal scales. ArcWatch-2 contributes to our Arctic wide sea-ice thickness monitoring programme performed from vessels and aircraft. During the cruise, we will measure the ice thickness by drone and helicopter while at ice stations we will conduct *in situ* measurements at higher spatial resolution. In addition, instruments will be deployed to cover seasonal mass balance parameters.

Melt ponds

Especially in the beginning of the cruise we hope to still find some larger melt ponds. Here we intend to fly automated photogrammetric drone surveys from which we can reconstruct the topography of the ice and under specific conditions also the bathymetry and hence the volume of melt ponds (Neckel et al., 2023, Fuchs et al., 2024). This is a highly experimental use case aiming to establish automated workflows for future drone missions over drifting sea ice.

Water vapor in the summertime central Arctic

- Here we aim to understand the spatio-temporal variability of summertime Integrated Water Vapor (IWV) and of the water vapor profile in the central Arctic region. Further we want to find answers on how surface conditions, i.e., open ocean, Marginal Ice Zone (MIZ), and sea ice, drive the atmospheric water vapor content and its vertical distribution and if we can identify a surface dependency or if the coupling to the surface is rather masked by large-scale transport mechanisms of water vapor.

Properties of Arctic mixed-phase clouds

- This objective relates to the spatio-temporal variability of the Lquid Water Path (LWP) of summertime Arctic clouds in the central Arctic and how it is linked to the radiative energy budget. Further we want to better understand the processes that regulate the formation, properties, precipitation, and lifetime of Arctic clouds.

Surface emissivity in the microwave spectrum

- Here we want to determine the spatio-temporal variability of Microwave (MW) emissivity of sea ice in the MIZ and the pack ice in the central Arctic. Further we want to assess the accuracy of models, databases, and satellite retrievals in representing the MW emissivity measurements. Finally we aim to evaluate the impact of surface condition-induced variability in surface emissivity on MWR satellite retrievals of IWV.

Ice navigation

Being able to accurately and safely navigate ice covered waters is the minimum foundation for all kinds of polar marine operations. In addition to close-proximity ice monitoring from the ship, satellite radar imagery (Synthetic Aperture Radar, SAR) has developed into the most promising tool to identify potentially navigable open leads and impassable ice ridges even beyond the ship's detection reach. While SAR images provide high spatial resolution and reliable images even during cloudy conditions and nighttime, its coarse temporal resolution does not account for the dynamic nature of drifting sea ice, which can move up to several kilometers per day. The initial satellite image becomes outdated rather quickly. Ice motion taking place between consecutive satellite acquisitions remains unknown and can only be estimated once the new image arrives. To overcome the data gap between consecutive images we plan to test and improve a novel algorithm that produces drift-corrected SAR imagery. The goal is to apply seaice drift data from various different onboard sources to determine the temporal limits of both, the algorithm and the various data products. Additionally, we want to learn how this drift-corrected SAR imagery is received by the nautical crew on board and what requirements they have for an operational product. Secondly and as part of the ongoing FastCast-2 research project (https://bmdv.bund.de/SharedDocs/DE/Artikel/DG/mfund-projekte/fast-cast2.html) we want to test AI-based optimized route suggestions under real-world conditions. Optimized routes are calculated using SAR imagery as well as seaice drift forecast models. They provide valuable route estimates that go beyond the visual/radar range available to the nautcial crew on board. Successfully optimized routing will make it easier for navigators to identify and chose safer, faster and more fuel-efficient pathways through the ice. The goal during PS144 is to share the FastCast-2 route suggestions with the nautical crew, potentially follow them and learn more about the factors that build trust in these machine-generated routes.

Work at sea

Airborne measurements

We will use airborne electromagnetic induction sounding to measure sea-ice thickness by helicopter surveys. We will fly the new AWI EM-Bird, along the entire cruise track, whenever there is sea ice. This system will reveal sea-ice thickness distribution functions on local scales (< 60 nm) around the vessel. Furthermore, we will conduct drone based lidar scans to measure the ice surface elevation around the ship which can be translated into ice thickness estimates during post-processing. We also want to test in how far drone imagery can be used for ice navigation and to validate AI generated route suggestions during the cruise.

During ice stations we will conduct automated drone grid flights for photogrammetric and lidar surveys including an in-flight ice drift correction. This way we can precisely map the single ice station floes and contribute to the development of surface descriptions, classifications, and the quantification of surface properties, such as surface albedo or melt pond depths.

Atmospheric measurements

We will operate a set of active and passive remote sensing instruments: a G-band differential absorption radar, a W-band cloud radar, two MWRs covering the K-, V-, and G-band frequency range, and total sky cameras in the visual (VIS) and infrared (IR) spectral range. The set of remote sensing instruments will be completed by a laser disdrometer for precipitation measurements and additional radiosondes to increase the frequency of launches on board the vessel during the workdays at sea. Additional atmospheric measurements include a uSonic anemometer for wind measurements as well as sun photometer measurements including microtops sun photometers to collect data for AERONET (remote sensing aerosol network).

Autonomous platforms

Among these platforms are Snow Buoys, SIMBA- and CRREL-type ice mass balance buoys, and weather stations. In collaboration with the French Service hydrographique et océanographique de la Marine (SHOM), 11 MetOcean SVP drifters will be deployed on ice floes evenly spaced along the cruise track to obtain rare barometric pressure measurements across a large area of the Arctic Ocean in support of numerical weather forecasting. The overall buoy work is strongly supported by the International Arctic Buoy Programme, and most of the data also feeds into the IABP database for public access. For this work a close cooperation with the physical oceanography section is intended.

Ice surface measurements

On a regular basis, the MWRs will be pointed towards the ocean/sea ice surface to measure the microwave emissions of the surface. These surface observations are complemented by VIS and IR camera data taken from the surface at high temporal resolution of up to 1 s which cover the field of view of the MWRs. In this way, microwave emissions of typical surface classes like sea ice, open water, and melt ponds will be measured.

We will conduct various measurements on the sea ice during the ice stations 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 and include:

- GNSS network for drift and reference measurements
- Melt-pond surveys to validate drone-based measurements
- Transect measurements of sea ice (total) thickness with GEM-2 sensors
- Transect measurements of snow depth with MagnaProbe sensors
- Supportive drilling and probing for other groups
- Vertical profiles of ice and snow temperature, salinity and density
- Snow stratigraphy (traditional snow pit and SnowImager)
- cm-scale surface roughness (photogrammetry)
- Snow and ice permittivity at 50 MHz

Supplemental observations (on board)

We will operate the Panomax camera installed above the crow's nest during the entire expedition, taking regular (e.g., 20 min intervals) images of the sea ice and weather conditions. Additional sea-ice observations are conducted from the bridge 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

Ice thickness and 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 and for the first time we will incorporate ice thickness retrievals from drone based lidar scanning. We will compare the ArcWatch-2 data to results from previous studies, including the MOSAiC drift and aircraft campaigns (e.g., IceBird, Belter et al., 2021). Comparisons will also include work with data from the International Arctic Buoy Program (IABP). All this will contribute to the monitoring of the dramatic thinning of sea ice in the central Arctic and along the Transpolar Drift.

Melt ponds

We want to establish workflows which can be used for autonomous mapping of ice floes including the processing of orthoimages and digital surface models. For this we will test automated grid flights of drones over drifting sea ice. If melt ponds are covered during these flights, we aim to reconstruct their bathymetry by means of photogrammetry. This will give the possibility to derive melt pond parameters such as geometry, volume and surface height over entire ice floes previously only available from *in situ* transect data (Webster et al., 2022, Fuchs et al., 2023).

Atmospheric measurements

The temperature and water vapor profile measurements and the measurements of mixed-phase cloud properties will contribute to high quality reference datasets of these quantities for the central Arctic sea-ice region. This is of particular interest for the evaluation of satellite microwave retrievals of IWV and LWP.

Our continuous observations will be used to assess both the impact of different surface conditions (i.e., MIZ and ice pack) on the atmospheric water vapor as well as potential spatial gradients of water vapor.

Key processes governing the evolution of mixed-phase clouds will be elucidated by embedding the radar measurements in a synergy with passive MWRs, a laser disdrometer, radiosondes, and the onboard ceilometer and rain gauge. We will derive LWP from the passive radiometer measurements. By combining LWP from radiometers and the dual-frequency radar synergy, we will improve the detection and profiling of supercooled liquid water layers.

Within the next months, the EarthCare satellite is expected to be launched. EarthCare will operate a 94 GHz cloud radar similar to the one in the VAMPIRE configuration. By that, we will provide some of the very few high latitude validation datasets.

Ice surface measurements

The ice surface measurements aim to increase the knowledge on microwave emissivity of the sea ice and its spatio-temporal variability at different frequencies at satellite footprint scales when Polarstern is moving through the ice. The emissivity measurements will help to understand the the influence of changing emissivities on satellite retrievals of IWV and LWP.

Measurements of the snow and ice surface (and its variability) during ice stations, ideally also within the footprint of the MWRs, will help to relate the (micro)physical properties like ice temperature profiles or snow density to the microwave signal and can help to evaluate and advance models of microwave emissions of snow and sea ice.

Ice navigation

Here we hope to successfully support the nautical crew of the vessel with AI based route suggestions. We also want to use drone flights to validate the latter and use the drone imagery on the bridge for ice exploration during the cruise.

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 (www.pangaea.de) within two years of the end of the cruise. 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.

This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 2, Subtopic 1.

In all publications based on this expedition, the **Grant No. AWI_PS144_05** 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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7. PELAGIC AND SEA-ICE BIOLOGY – PSB

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Grant-No. AWI_PS144_06

Objectives

In light of rapid environmental changes in the Arctic Ocean, notably unprecedented ice melt and alterations in oceanic circulation patterns, there is a pressing need to understand the ecosystem dynamics in this remote region. The Central Arctic Ocean Fisheries Agreement (**CAOFA**) underscores the urgency of this endeavor, emphasizing the necessity to advance scientific knowledge before considering ecologically sustainable fisheries development. Our expedition ArcWatch-2 is part of the **ArcWatch** campaign of 4 consecutive expeditions in the Central Arctic Ocean (CAO) between 2023 and 2027, as part of the *Programme-Oriented-Research (POF) IV* programme of the Helmholtz association. In order to understand impacts and predict the future development of the coupled physical-chemical-biological system in the Arctic Ocean, ArcWatch in conjunction with MOSAiC 2019-2020, the approximately 20 Synoptic Arctic Survey (SAS) expeditions 2020-2022, and various observing frameworks by national and international networks (e.g. FRAM, the Nansen Legacy, SUDARCO, Arctic PASSION), set the scene for systematic interdisciplinary long-term observations in the Arctic Ocean. This is accomplished by sampling of a predefined of set of physical, chemical and biological core parameters, applying unified standards and protocols across temporal and spatial scales as part of time series observation in the Arctic Ocean (Fig. 1). This approach provides us with adequate information to estimate consequences of global change on Arctic ecosystems, including the remote CAO.

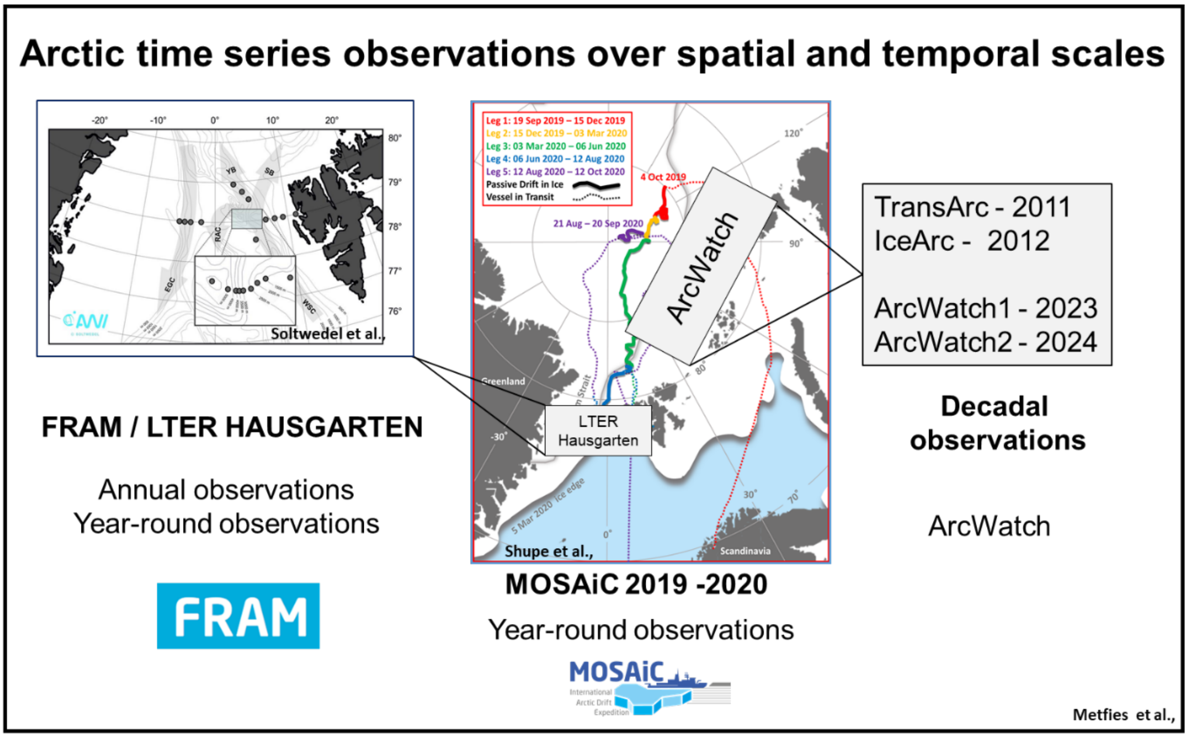

Fig. 1: AWI's coordinated interdisciplinary Arctic observations over different spatial and temporal scales (Figure provided by K. Metfies, AWI).

Besides research related to POF IV, work of parts of the team Pelagic- and Sea-Ice Biology (PSB) is performed under the auspices of the EU-tender *SciCAO* which aims to broaden the knowledge basis on the distribution of fish and their prey in the CAO as part of the Joint Programme for Scientific Research and Monitoring (JPSRM) of the CAOFA. JPSRM-relevant sampling is coordinated with the project Korean Polar Research Institute (KOPRI) programme *Korea-Arctic Ocean Warming and Response of Ecosystem* (K-AWARE) on expedition ARA15B with *Araon* in the Pacific Arctic.

The overarching objective of team PSB is to elucidate the biogeochemical and ecological processes governing primary productivity, biodiversity, trophic interactions and the biological carbon pump within the CAO. Through a systematic interdisciplinary approach integrating physical oceanography, sea-ice physics, marine biology and biogeochemistry we aim to provide crucial insights into the ecological functioning of the unique 3.3 million km^2 ecosystem around the North Pole that until recently was permanently ice-covered. We provide a present status report and aim to predict future scenarios with the ongoing climate change. The results of ArcWatch-2 will produce crucial information for the development of effective conservation and management strategies in the CAO. Our expedition aims to achieve the following specific goals:

1. **Collect core parameters of ArcWatch and POF IV for long-term observations:** We will comprehensively assess the biological landscape of the CAO ecosystem, ranging from microbial communities to fish populations, while elucidating trophic linkages and the biological carbon pump. This investigation will encompass sampling of particulate organic matter (POM), ice algae, phytoplankton, zooplankton, microbial DNA and cryogenic gypsum across the water column and sea ice habitats. Phytoplankton analysis will be complemented by high-resolution taxonomic analysis from KOPRI.

2. **Investigate the distribution and abundance of fish and their prey in the CAO (SciCAO):** Through a hydroacoustic survey and sampling of fish, zooplankton and metazoan eDNA, we will document the spatial distribution and abundance of fish species within the CAO, along with their associated prey communities. Transcriptomic studies in conjunction with ecophysiological proxies of collected fish in comparison to existing field and laboratory samples will be used to assess the status and adaptational potential of the specimens from CAO. This study will provide essential baseline data for the JPSRM.
3. **Contribute to the record on foraminifera in the changing CAO in relation to paleo-oceanographic sediment records:** By examining foraminifera populations in zooplankton samples collected from the CAO, we aim to compare present changes in relation to past environmental conditions.

Work at sea

The biological and biogeochemical parameters sampled during ArcWatch-2 complement each other for the purpose of obtaining a system understanding of biodiversity and ecosystem functions. They are organised in three closely interconnected work packages (WP). Table 1 provides an overview of the different parameters sampled and their specific methods.

WP1 ArcWatch core parameters and other POF IV-related sampling

<u>Water column.</u> Using water samples collected with the **CTD rosette**, we will sample POM for various parameters (e.g. carbon, nitrogen, pigments, trophic biomarkers, eDNA for analyses of eukaryotic microbial biodiversity and fish distribution, see Tab. 1) from different depths, including the subsurface, the chl *a* max, 50-100 m, the Atlantic Water, and the Arctic Deep Water. In most cases, the sampled water will be filtered on board on appropriate filters, and the filters are stored frozen until analysis in the home laboratory. In addition, eDNA for analyses of eukaryotic microbial biodiversity and fish distribution will be sampled with an **AutoFIM**, which collects underway-water samples at defined stations from a seawater intake at about 11 m depth near the ship's bow. Particle distribution in the water column will be recorded with an Underwater Vision Profiler (**UVP**). The mesozooplankton community will be sampled with a **Multinet** (MN, Hydrobios, 0.25 m^2 opening, 150 µm mesh) at 5 standard depths (1,500-1,000, 1,000-500, 500-200, 200-50, 50-0 m). Macrozooplankton will be sampled with a multiple-opening Rectangular Midwater Trawl (**M-RMT**, 8 m^2 opening, 5 mm mesh) sampling three depth strata (1,000-200, 200-50, 50-0). At selected ice stations, macrozooplankton will also be sampled from 1,000 m to the surface with a 2-m diameter ring net (**MIK net**, 3.14 m^2 opening, 1 mm mesh). Taxonomic samples from these nets will be preserved on a formaldehyde-seawater solution, and later analysed at AWI with a ZooScan. For trophic biomarker and pollutant analysis (bulk stable isotope analysis (BSIA), fatty acid composition and isotopic fractionation (FA-CSIA, Kohlbach et al. 2016), amino acid carbon isotopes (AA-CSIA, Vane et al. 2023), pollutants, macrozooplankton will be collected from catches of the RMT and the MIK net, and mesozooplankton will be collected with a Bongo net. Foraminifera will be collected by **multinet** (50 µm mesh; planktonic foraminifera) and **minicorer** (benthic foraminifera) to complement existing data covering several decades. Foraminifera data will be used to document recent Atlantification and warming and to reconstruct past interglacial conditions.

<u>Sea ice.</u> On the **sea-ice stations** conducted during ArcWatch-2, we will sample the same general parameters as in the water column (Tab. 1). To this end, we will establish a sea-ice biogeochemical sampling site on each ice station (Fig. 2). We will sample at least one temperature / salinity core, one nutrient core, and 6-10 biological / biogeochemical cores with a Kovacs 9-cm diameter **ice corer**. We will sample under-ice water and meltpond water with

peristaltic **hand pumps**. Ice cores will be sectioned in four sections, according to the SAS Oden Standard Operating Procedure (SOP; Snoeijs-Leijonmalm et al. 2022a): bottom 10 cm, lower center-piece, upper center-piece, top 10 cm. The ice core sections for all parameters except salinity and nutrients will be pooled and melted in filtered seawater at 4°C before filtration. Temperature / salinity and nutrient cores will be subdivided into 10 cm sections which are individually melted at room temperature, and analysed immediately after complete melt. On an opportunistic basis, we will deploy **baited traps** to sample ice amphipods and polar cod (Snoeijs-Leijonmalm et al. 2022). Depending on sea-ice conditions (see section on SciCAO sampling below), we will sample polar cod *Boreogadus saida* and other under-ice fauna with a Surface and Under-Ice Trawl (**SUIT**) equipped with a **CTD** with a **fluorescence sensor** and **hyperspectral radiometers** to estimate ice algae biomass. To calibrate ice-algae biomass estimates from hyperspectral profiles, we will conduct L-arm measurements with a hyperspectral sensor during the sea-ice stations (Castellani et al. 2020). To elucidate the composition, quantity and distribution of cryogenic minerals within the ice and upper water column minerals are collected with different cryogenic nets (WP1, WP2) attached to classic gears and by extended water sampling (CTD, water pumps).

Fig. 2: Example of the preparation of an ice station during the Synoptic Arctic Survey with RV Oden in 2021 (Snoeijs-Leijonmalm et al. 2022a).

WP2 SciCAO sampling

The EU-project *SciCAO* aims to contribute to baseline knowledge on the distribution of fish in the CAO and the ecosystem supporting it. *SciCAO* sampling will therefore be complementary to the ArcWatch core parameter sampling, and results will be obtained in combined analysis of both sets of parameters.

The distribution of fish and its zooplankton prey in the water column will be measured continuously throughout the expedition with the **EK80** echosounder of *Polarstern*. The EK80 provides continuous profiles of hydroacoustic backscatter at 18, 38, 70, 120 and 200 kHz from the surface to about 800 m depth. The EK80 survey will be conducted according to the SOP established for JPSRM sampling during the *European Fish Inventory of the Central Arctic Ocean* (EFICA) project (2019-2023; Snoeijs-Leijonmalm et al. 2021). The EK80 will be calibrated using an underwater robot positioning a calibration sphere according to a method established during MOSAiC (Snoeijs-Leijonmalm et al. 2022b). In order to estimate abundance and biomass of fish and zooplankton from acoustic backscatter data, it is necessary to know the species composition and size distribution of animals in the water column. While the size range of zooplankton is covered by the net sampling of the ArcWatch core parameters, the pelagic fish community will be sampled with a **pelagic fish trawl**, whenever ice conditions allow. The suitability of the research area for trawling will be assessed during the cruise with satellite images and helicopter recognition. The pelagic trawl will be used if the probability of large (at least 2-3 nautical miles) open leads is deemed high enough to allow for safe deployment and recovery of the net. The pelagic trawl will target the Atlantic Water layer near the North Pole and in the Eastern Amundsen Basin (100-800 m depth, where most fish are expected to occur (Fig. 2; Snoeijs-Leijonmalm et al. 2022b), as well as hitherto not sampled areas in the Canada Basin west of the Lomonosov Ridge. If the CAO has a closed sea-ice cover with no openings that allow for safe trawling, we will focus on the sampling of ice-associated polar cod with the SUIT. Pelagic fish will then be sampled with **longlines** from sea-ice stations, following EFICA SOPs (Snoeijs-Leijinmalm et al. 2021). To this end, baited longlines will be deployed at least 500 m away from the ship and any other installations with deep-hanging wires at the earliest possible moment prior to the commencement of an ice stations, and recovered at the latest possible time. The presence of fish in the water column will further be investigated by means of **eDNA** sampled near the surface, in the Atlantic Water layer, and below.

Fish caught by different nets, traps or longlines will be dissected on board in order to obtain samples for diet, otolith analysis, trophic biomarkers, fecundity, physiological condition, transcriptomic analyses, and population genomics. These samples will be preserved according to their EFICA SOPs (Snoeijs-Leijonmalm et al. 2021), and analysed in the home laboratories. eDNA sequences will be analysed from the COI, 12S, 16S and 18S amplicons, and metazoan species composition will be obtained from international reference databases (e.g. MIDORI). Polar cod will be targeted with a new specific primer from the mitochondrial D-loop region, allowing for analysis of spatial patterns in relative abundance (Kawakami et al. 2023). For the estimation of the field metabolic rate (FMR) during the life history of the caught fish based on otolith calcium carbonate $\delta^{13}C$ values (Trueman et al. 2023), we will also sample the $\delta^{13}C$ of dissolved organic carbon (DIC) in the water surface and column, and the under-ice habitat.

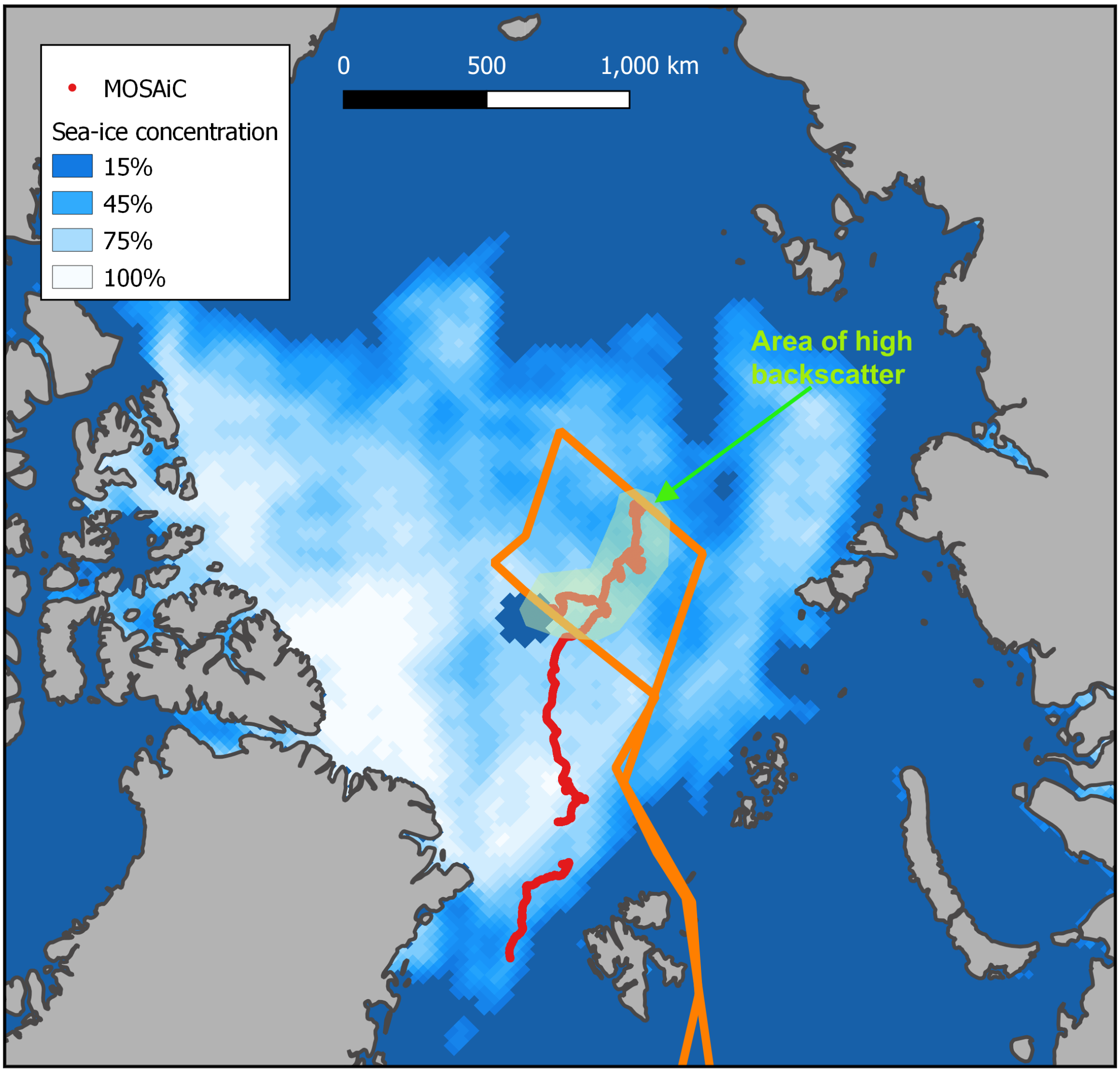

Fig. 2: Planned cruise track of ArcWatch-2 (PS144), superimposed on MOSAiC track and approximate area of elevated backscatter in the CAO (Snoeijs-Leijonmalm et al. 2022b)

WP3 Other project-based sampling

Eukaryote DNA diversity. We will collect eDNA from sea-ice and pelagic samples to characterize the eukaryotic microbial community composition to address the dynamics of the cryo-pelagic coupling in biodiversity in autumn with special emphasis on the re-freezing. These data will be used in combination with data collected within the framework of FRAM and MOSAiC to infer on linkages between sea-ice coverage and eukaryotic microbial biodiversity. This information will be used as part of the INSPRIES PhD project of Jannis Hümmling and the EU-Project **OBAMA_Next** to develop species distribution models that will eventually suggest scenarios for eukaryotic microbial biodiversity, dynamics and distribution in a seasonally ice-free Arctic ocean.

Phytoplankton diversity. We study the influences of changes in sea ice melting and oceanic circulation patterns on the phytoplankton community distributions. To understand the ecosystem response in the pan-Arctic region, sampling is conducted during the ArcWatch-2 expedition in the Atlantic Arctic Ocean as part of the JPSRM programme. The results are compared with those obtained through the **K-AWARE** expedition in the Pacific Arctic Ocean. Ice algae are collected from sea-ice cores and analyzed using microscope in a laboratory after the cruise. Phytoplankton in flow-through seawater supplied from the ship is analyzed in real time using IFCB. To calibrate the results of IFCB, samples for microscopic analysis, photosynthetic pigment concentration, and picophytoplankton abundance are collected in flow-through seawater and each is analyzed in the laboratory using microscopy, HPLC, and flow cytometer, respectively.

Trophic biomarkers and pollutants. To elucidate trophic relationships and dependencies within the lower trophic food web of the CAO under current environmental conditions, samples of ice algae (ice corer), phytoplankton (CTD), zooplankton (different nets; WP1) and fish (pelagic trawl, SUIT; WP2) will be collected for analysis of biomolecules that can be used for indicating the trophic transfer of carbon from specific primary producer groups to higher trophic levels. This will include the relative composition of fatty acids and highly branched isoprenoids, and isotopic ratios of bulk organic material as well as fatty acids and amino acids. The main objective is to quantify the dependency of the food web on ice algae *vs.* specific phytoplankton groups, and trace the transfer of these carbon sources to zooplankton and fish. To simultaneously identify the pollution burden of the lower trophic food web, major contaminants (POPs, PFAS) will be identified and quantified in the same species. Collected samples will significantly contribute to the Helmholtz Young Investigator project ***Double-Trouble*** aiming at understanding the trophic structure of the CAO food web under cumulative stress from warming and (increasing) anthropogenic pollution. The samples will complement samples of the same parameters collected during a CAO expedition in July/August 2024 led by the Norwegian Polar Institute.

Tab. 1: Overview of parameters to be sampled by team PSB during ArcWatch-2. Hbt = habitat; ice = sea-ice habitat (including ice-water interface); RSoB = responsible scientist on board; PT = pelagic trawl; board; wtr = water column.

Parameter	Hbt	Devices	RSoB	Owner	Projects
Chlorophyll a concentration	wtr, ice	CTD rosette, ice corer	J. Hümmling	AWI	ArcWatch (POF IV)
Particulate Organic Matter (POC/PON)	wtr, ice	CTD rosette, ice corer	H. Flores	AWI	ArcWatch (POF IV)
Microalgae abundance & diversity	wtr, ice	CTD rosette, ice corer	H. Flores	AWI	ArcWatch (POF IV)
Pigment composition	wtr, ice	CTD rosette, ice corer	H. Flores	AWI	ArcWatch (POF IV)
POM stable isotope composition (C&N)	wtr, ice	CTD rosette, ice corer	H. Flores	AWI	ArcWatch (POF IV)
POM trophic biomarkers	wtr, ice	CTD rosette, ice corer,	H. Flores	AWI	ArcWatch (POF IV) DoubleTrouble
Sinking particles	wtr	UVP	H. Flores	AWI	ArcWatch (POF IV)
eDNA (protists)	wtr, ice	CTD rosette, ice corer, AutoFIM	J. Hümmling	AWI	ArcWatch (POF IV)
Invertebrate trophic biomarkers	wtr, ice	Zooplankton nets, SUIT	H. Flores	AWI	ArcWatch (POF IV) DoubleTrouble
Macrofauna abundance & diversity	wtr, ice	Zooplankton nets, SUIT	H. Flores	AWI	ArcWatch (POF IV)
Macrofauna biomass	wtr, ice	Zooplankton nets, SUIT	H. Flores	AWI	ArcWatch (POF IV)
Mesofauna abundance & diversity	wtr, ice	Zooplankton nets, SUIT	H. Flores	AWI	ArcWatch (POF IV)

Parameter	Hbt	Devices	RSoB	Owner	Projects
Ice algae mesoscale distribution	Ice	SUIT	H. Flores	AWI	ArcWatch (POF IV)
Cryogenic minerals	wtr, ice	CTD rosette, ice corer	K. Fazieva	AWI	POF IV
Hydroacoustic backscatter	wtr	EK80, WBAT	S. Sakinan	AWI	SciCAO
Fish species composition	wtr	PT, longlines, traps, SUIT	M. Lucassen	AWI	SciCAO
Fish condition	wtr	PT, longlines, traps, SUIT	M. Lucassen	AWI	SciCAO
Fish age and life-history from otoliths	wtr	PT, longlines, traps, SUIT	K. Vane	TI	SciCAO
Fish population genetics	wtr	PT, longlines, traps, SUIT	M. Lucassen	EV-ILVO	SciCAO
Fish diet	wtr	PT, longlines, traps, SUIT	M. Lucassen	WMR	SciCAO
Fish trophic biomarkers	wtr	PT, longlines, traps, SUIT	M. Lucassen	AWI	SciCAO DoubleTrouble
Metazoan eDNA	wtr, ice	CTD rosette, ice corer	H. Flores	AWI	SciCAO
Foraminifera abundance and diversity	Wtr, seafloor	Multinet, Minicorer	K. Fazieva	AWI	POF IV
Ice algae	Ice	Ice corer	Y. Lee	KOPRI	ArcWatch (POF IV) K-AWARE
Phytoplankton species abundance	wtr	Flow-through seawater, IFCB	Y. Lee	KOPRI	ArcWatch (POF IV) K-AWARE
Picophytoplankton abundance	wtr	Flow-through seawater, Flow cytometer	Y. Lee	KOPRI	ArcWatch (POF IV) K-AWARE
Phytoplankton species abundance	wtr	Flow-through seawater, Microscope	Y. Lee	KOPRI	ArcWatch (POF IV) K-AWARE
Photosynthetic pigments	wtr	Flow-through seawater, HPLC	Y. Lee	KOPRI	ArcWatch (POF IV) K-AWARE
Pollutants	wtr, ice	CTD rosette, ice corer, zooplankton nets, SUIT, PT	H. Flores	AWI	DoubleTrouble

Preliminary (expected) results

The unique geographical scope of ArcWatch-2, covering the Eurasian Basin, but extending into the Canada Basin, will enable us to sample in a rarely-visited area. With the results of the team PSB, we expect to make significant contributions to closing important knowledge gaps about the CAO ecosystem and the ecosystem functions and services it provides. Our results will contribute, among other outcomes, to:

- A comprehensive understanding of patterns of planktonic and sympagic species distribution and diversity, from the level of genes to whole organisms;
- urgently needed knowledge about pelagic fish distribution, their physiological condition, diet and migration patterns in the CAO, with respect to the CAOFA;

- a better understanding of the habitat use of the ecological key species polar cod;
- a better understanding of cryo-pelagic coupling in the CAO, including key processes such as cryogenic ballasting, primary production and trophic transfer;
- a comparison of biological patterns between the eastern CAO and the western side of the CAO and the Bering and Chukchi Seas visited by the Korean icebreaker Aaraon, and areas sampled by other research campaigns.

As part of the coordinated observation framework ArcWatch, these findings will also contribute to long-term observation of the changing Arctic ecosystem.

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). SciCAO data and SOPs will be published, in agreement with the JPSRM data policy, in appropriate repositories such as **Zenodo** or PANGAEA, and made accessible in international data portals, e.g. the European Marine Observation and Data Network (**EMODnet**). For biodiversity data, we will follow the DarwinCore standard and use the DarwinCore archive to make data available in **OBIS** and **GBIF**.

This expedition was supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 6, Subtopic 1-3.

In all publications based on this expedition, the **Grant No. AWI_ PS144_06** 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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Vane K, Cobain MRD, Trueman CN, Vonnahme TR, Rokitta S, Polunin NVC, Flores H (2023) Tracing basal resource use across sea-ice, pelagic, and benthic habitats in the early Arctic spring food web with essential amino acid carbon isotopes. Limnol Oceanogr n/a https://doi.org/10.1002/lno.12315

APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

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US.USF	University of South Florida College of Marine Science 140 7th Avenue South St.Petersburg FL 33701 USA
US.WHOI	Woods Hole Oceanographic institution 266 Woods Hole Road MS #2 Woods Hole MA 02543 United States

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Allerholt	Jacob	DE.AWI	Technician	Oceanography
Amon	Rainer	US.TA&M	Scientist	Oceanography
Bahlmann	Jonathan	DE.DRIFT-NOISE	Scientist	Geophysics
Bettinelli	Alexandra	DE.AWI	PhD student	Biology
Brauer	Jens	DE.NHC	Pilot	Helicopter Service
Buehler	Linnea	DE.UNI-KOELN	PhD student	Meteorology
Faizieva	Kamila	A.UW	PhD student	other geo sciences
Flores	Hauke	DE.AWI	Scientist	Biology
Fu	Ke-Hsien	TW.NARM	Scientist	Oceanography
Gäng	Frederik	DE.UOL	PhD student	other geo sciences
Geibert	Walter	DE.AWI	Scientist	other geo sciences
Gischler	Michael	DE.NHC	Pilot	Helicopter Service
Gorniak	Rebecca	DE.AWI	Student (Master)	Biology
Heuzé	Céline	SW.UGOT	Scientist	Oceanography
Hoppmann	Mario	DE.AWI	Scientist	Oceanography
Huhn	Olliver	DE.UNI-BREMEN	Scientist	Oceanography
Hümmling	Jannis	DE.AWI	PhD student	Biology
Kaphegyi	Insa	DE.UHH	Student (Bachelor)	Biology
Kaphegyi	Kari	A.UI	Student (Master)	Biology
Kolar	Jonathan	DE.UNI-BREMEN	Student (Master)	Physics
Kordes	Thomas	DE.AWI	Engineer	Engineering Sciences
Koschnick	Nils	DE.AWI	Engineer	Biology
Krisch	Stephan	DE.GEOMAR DE.TUBS	Scientist	Oceanography
Lee	Youngju	KOR.KOPRI	Scientist	Biology
Lucassen	Magnus	DE.AWI	Scientist	Biology
McOscar	Dwayne	DE.NHC	Technician	Helicopter Service
Mech	Mario	DE.UNI-KOELN	Scientist	Meteorology
Murawski	Sandra	DE.AWI	Technician	Biology
Neckel	Niklas	DE.AWI	Scientist	Glaciology
Neumann	Zoe	DE.CAU	Student (Bachelor)	Geology
Palmer	Freya	UK.UEDINGBURGH	Scientist	Oceanography
Pin	Aude	DE.GEOMAR	Student (Master)	Oceanography

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Rabe	Benjamin	DE.AWI	Scientist	Oceanography
Risse	Nils	DE.UNI-KOELN	PhD student	Meteorology
Rode	Joerg	DE.NHC	Engineer	Engineering Sciences
Rodrigues	Andreia	FR.MIOM	Scientist	Biology
Rohleder	Christian	DE.DWD	Technician	Logistics
Ruan	Yaqing	DE.GEOMAR	PhD student	Oceanography
Rueckert	Janna	DE.UIP	Scientist	Physics
Sakinan	Serdar	NL.WMR	Scientist	Biology
Scheiwiller	Marcel	CH.ETH	PhD student	Oceanography
Stimac	Ingrid	DE.AWI	Technician	Chemistry
Suresh	Simran	DE.AWI	PhD student	Oceanography
Suter	Patrick	DE.DWD	Scientist	Meteorology
Tippenhauer	Sandra	DE.AWI	Scientist	Oceanography
Torres Valdes	Sinhue	DE.AWI	Scientist	Oceanography
Trace-Kleeberg	Sunke	UK.USOTON	PhD student	Oceanography
van Dorssen	Michiel	NL.vDMet	Technician	Biology
Vane	Kim	DE.AWI	Scientist	Biology
Voelkner	Christian	DE.AWI	Engineer	Biology
Vortkamp	Martina	DE.AWI	Technician	Biology
Wong	Carmen	SW.UGOT	PhD student	other geo sciences
Zhu	Jialiang	CN.OUC	PhD student	Oceanography
Zimmermann	Jan	DE.UHH	Student (Bachelor)	Biology

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

No.	Name	Vorname	Position
1	Schwarze	Stefan	Kapitän
2	Grundmann	Uwe	1.NO
3	Eckenfels	Hannes	1.NO / 2. NO Ladung
4	Weiß	Daniel	2.NO
5	Peine	Lutz	2.NO
6	Meier	Jan	Bootsmann
7	Buchholz	Joscha	FA/D
8	Möller	Falko	FA/D
9	Schneider	Denise	FA/D
10	Schade	Tom	FA/D
11	Decker	Jens	FA/D
12	Mahlmann	Oliver	FA/D
13	Bäcker	Andreas	FA/D
14	Siegel	Kilian	FA/D
15	Keller	Jürgen	Zimmermann
16	Niebuhr	Tim	FA/D (AB)
17	Ziemann	Olaf	LTO
18	Rusch	Torben	2.TO
19	Krinfeld	Oleksandr	2.TO
20	Jassmann	Marvin	2.TO / 3.TO
21	Loew	Caspar	FA/M
22	Stubenrauch	Paula	FA/M
23	Töben	Carlotta	FA/M
24	Buchholz	Karl	FA/M
25	Probst	Lorenz	FA/M
26	Plehn	Marco	Fitter / Storekeeper
27	Pommerencke	Bernd	Elektro-Ingenieur (SET)
28	Krüger	Lars	Elektroniker
29	Frank	Gerhard	Elektroniker

No.	Name	Vorname	Position
30	Zivanov	Stefan	Elektroniker
31	Winter	Andreas	Elektroniker
31	Skrzipale	Mitja	1. Koch
32	Fehrenbach	Martina	2. Koch
33	Loibl	Patrick	2. Koch
34	Witusch	Petra	1. Steward
35	Ilk	Romy	2. Steward / Nurse
36	Stocker	Eileen	2. Steward
37	Golla	Gerald	2. Steward
38	Holl	Claudia	2. Steward
39	Shi	Wubo	Messe / Wäscherei
40	Chen	Jirong	Messe / Wäscherei
41	Chen	Quanlun	Messe / Wäscherei
42	Guba	Klaus	Schiffsarzt