ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

EXPEDITION PROGRAMME PS106

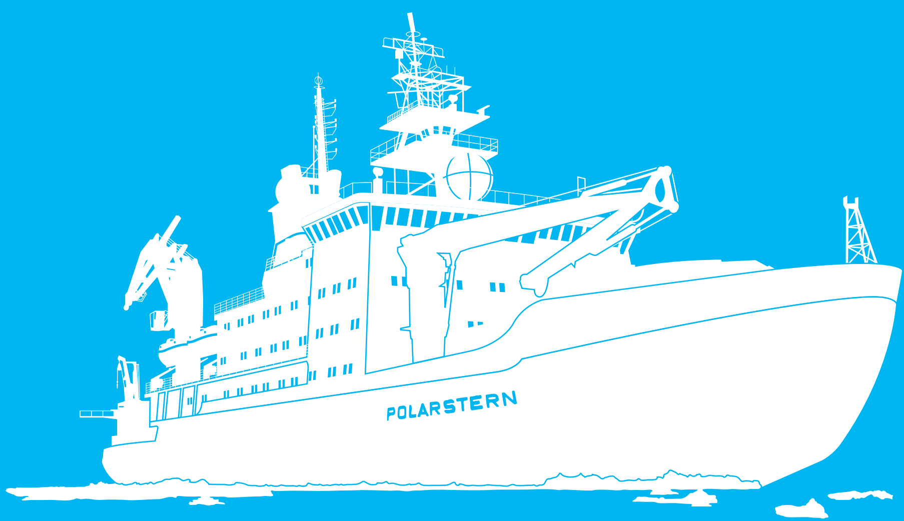
# Polarstern

**PS106.1**
**Bremerhaven – Longyearbyen**
**23 May 2017 - 21 June 2017**

**PS106.2**
**Longyearbyen - Tromsø**
**23 June 2017 - 20 July 2017**

Coordinator: Rainer Knust

Chief Scientists: PS106.1 Andreas Macke
PS106.2 Hauke Flores



Bremerhaven, März 2017

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**Andreas Macke**

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**Coordinator**
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# 1. ÜBERBLICK UND FAHRTVERLAUF

A. Macke (TROPOS)
H. Flores (AWI)

Die Expedition PS106 sticht am 23. Mai 2017 von Bremerhaven aus in See, um auf direktem Kurs einen Bereich in der zentralen Arktis zu erreichen, der eine 14tägige Drift an einer Eisscholle zur kontinuierlichen Erfassung des Energiehaushaltes am Boden und des Zustands der bewölkten Atmosphäre ermöglicht (Projekt PASCAL). Auf der Hinfahrt werden täglich Oberflächenwasserbeprobungen vorgenommen und diverse autonome ozeanische Messsysteme ausgesetzt. Parallel sind auf der Eisscholle meereisphysikalische, biologische und biogeochemische Messungen im Meereisbereich geplant. Im Anschluss fährt *Polarstern* nach Longyearbyen mit Ankunft am 21. 6. 2017, um von dort weiter im arktischen Eis östlich von Spitzbergen Meeresbiologie mit Schwerpunkt Polardorsch (Survival of Polar Cod in a Chaning Arctic Ocean: SiPCA), Meereisphysik, ozeanographische Messungen und Atmosphärenfernerkundung zu betreiben. Von Fahrtbeginn bis Ende Juni 2017 wird *Polarstern* von den AWI-Polarflugzeugen Polar 5 und Polar 6 angeflogen um die schiffs- und bodengebundenen Messungen durch flugzeuggetragene *in-situ* Messungen und Fernerkundung von Aerosol und Wolken zu ergänzen. Die Expedition PS106 endet am 20.7.2017 in Tromsø. Die atmosphärischen Messungen finden größtenteils im Rahmen des Sonderforschungsbereiches TR 172 "Arctic Amplification" statt. Die gesamte Fahrtroute ist in Abbildung 1.1 dargestellt.

Die Polargebiete sind wichtige Bestandteile des globalen Klimasystems. Die großflächige Schnee- und Eisbedeckung beeinflusst maßgeblich die Bodenenergiebilanz, welche wiederum stark an die atmosphärische und ozeanische Zirkulation gekoppelt ist. Das Wechselspiel verschiedener arktischer Rückkopplungsmechanismen ist dabei noch nicht vollständig verstanden. So ist z.B die Kopplung zwischen Meereis, Wolken und Aerosol in der Übergangszone zwischen offenem Ozean und Meereis bislang noch nicht gut verstanden. Daher soll im Projekt **PASCAL** (Physical feedbacks of Arctic PBL, Seaice, Cloud And Aerosol; PS 106.1) dieser Aspekt untersucht werden, um letztlich unser Verständnis der aktuellen dramatischen Abnahme des arktischen Meereises im nordhemisphärischen Sommer zu erhöhen. Zu diesem Zwecke liefern die TROPOS-OCEANET- und Aerosol-Instrumentierung an Bord von *Polarstern* sowie weitere spektrale Strahlungsmessungen die Oberflächenenergiebilanz und eine detaillierte Charakterisierung der Oberfläche, der Wolken und des Aerosols. Während *Polarstern* im Meereis verbleibt werden identische Messungen auf der AWIPEV Base (German – French Research Base) in Ny-Ålesund nahe des offenen Ozeans vorgenommen. Die Messungen auf *Polarstern* und der AWIPEV Base werden durch koordinierte Flüge der AWI Messflugzeuge Polar 5 und Polar 6 zwischen den Stationen und entlang des Gradienten der arktischen Meereiskonzentration begleitet. Diese luftgetragenen Messungen werden durch weitere Messungen der Grenzschichtstruktur (mittlere und turbulente Größen) mittels Fesselballons und mehrerer kleiner "Unmanned Airborne Vehicles" (UAV's) unterstützt. Die Ballonaufstiege und UAV's werden von einer Eisstation in der Nähe der *Polarstern* aus geleitet. Parallel werden auf der Eisscholle ozeanographische, meereisphysikalische und biologisches Arbeiten durchgeführt.

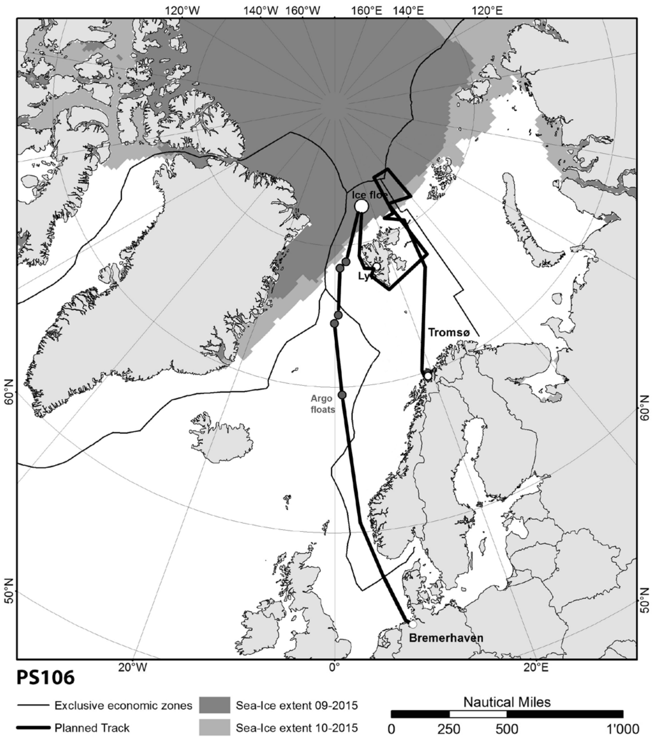


*Fig. 1.1: Planned cruise track of Polarstern expedition PS106. Black dots denote ARGO floats and SVP-B Drifter (operational meteorological / oceanographic drifting buoy) deployments*

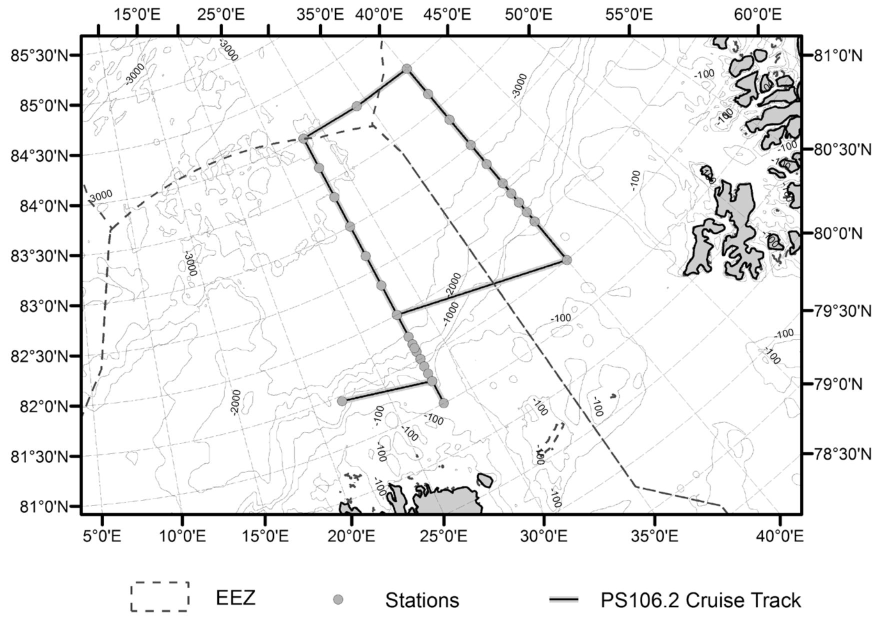


*Fig. 1.2: Research area of SiPCA (PS 106.2). The black line indicates the planned cruise track. dashed line = border of Russian EEZ. Dots indicate approximate positions of biological and oceanographic sampling stations*

In arktischen Ökosystemen kommt dem weit verbreiteten Polardorsch *Boreogadus saida* eine Schlüsselrolle zu, da er eine Hauptnahrungsquelle für Robben und Seevögel ist. Junge Polardorsche nutzen häufig den Lebensraum an der Unterseite des Meereises, der ihnen als Jagdrevier und Unterschlupf vor Räubern dient. Bedingt durch den Klimawandel vermindert sich die räumliche Ausdehnung des Untereis-Lebensraumes zusehends. **SiPCA** (Survival of Polar Cod in a Chaning Arctic Ocean; PS 106.2) möchte die Bedeutung des Meereises für den Polardorsch in der Barents-See und dem angrenzenden Arktischen Ozean genauer untersuchen (Abb. 1.2). Die räumliche Verteilung des Polardorsches, seiner Nahrungs–grundlagen, seiner Fressfeinde und anderer Umweltparameter sollen simultan beprobt werden. Auf mehreren Meereisstationen werden die physikalischen und bio-geochemischen Eigenschaften sowie die Biodiversität von Meereis und Schmelztümpeln untersucht. Im Rahmen eines parallel durchgeführten Forschungsprojektes sollen Atmosphärenpyhsi-kalische und –chemische Messungen zur Vertikalstruktur der Atmosphäre und zur Energie-bilanz an der Meeresoberfläche durchgeführt werden. Am Ende der Expedition wird wenn möglich die Eisscholle von PS 106.1 angefahren, um zurückgelassene Instrumente zu bergen. Die auf dieser Expedition gewonnenen Daten sollen u.a. helfen, den Kohlenstofffluss zwischen Meereis, Polardorsch und Warmblütern zu quantifizieren und die Bedrohung überlebenswichtiger Habitate für den Polardorsch durch den Klimawandel abzuschätzen. Die Arbeiten finden überwiegend in eisbedeckten Gewässern statt, so dass je nach Ausbreitung und Dichte des Eises der genaue zeitliche und räumliche Verlauf der Route in weiten Grenzen von dem geplanten Verlauf abweichen kann.

Das Projekt **TEMPO** (Evolution of Melt POnd characteristics in different Arctic sea ice) zielt darauf ab, das Verständnis der raum-zeitlichen Dynamik der Schmelzwassertümpel sowie über deren Rolle im arktischen Klima- und Ökosystem zu verbessern. Im Rahmen von TEMPO wird eine Anwenderroutine helikopterbasierte Sensoren entwickelt, welche die Ableitung der wichtigsten Parameter von Schmelzwassertümpeln (Größe, Bathymetrie, optisch aktive Wasserinhaltsstoffe) und des umgebenden Meereises (Reflexionsverhalten, Albedo) ermöglicht. In einem weiteren Schritt soll diese Anwendung für die Auswertung von Satellitendaten erweitert werden. Diese Anwendungen sollen ein flächenhaftes Monitoring der raum-zeitlichen Entwicklung von arktischen Schmelzwassertümpeln ermöglichen. Um essentielle Daten für die Entwicklung der Routine sowie zur Validierung der Ergebnisse zu generieren, soll eine möglichst breite Datenbasis an helikopterbasierten, multi- und hyperspektralen Daten sowie von feldbasierten Messungen geschaffen werden.

### Allgemeine Erklärung zum Datenmanagement

Falls in den folgenden Abschnitten nicht anderweitig spezifiziert, wird die Verarbeitung und Qualitätskontrolle aller Daten in den jeweiligen Heimateinrichtungen durchgeführt. Sobald die Daten verfügbar sind, werden diese auf Nachfrage den übrigen Fahrtteilnehmern bereitgestellt. Abhängig von der Fertigstellung akademischer Arbeiten und Publikationen werden die Daten innerhalb von 1 - 2 Jahren in PANGAEA archiviert.

# SUMMARY AND ITINERARY

The Polar Regions are important components in the global climate system. The widespread surface snow and ice cover in Polar Regions strongly impacts the surface energy budget, which is tightly coupled to global atmospheric and oceanic circulations. The interaction of different Arctic feedback mechanisms is not yet completely understood. For example, the coupling of sea ice, clouds and aerosol in the transition zone between open ocean and sea ice has not been well investigated so far. Therefore, this issue will be addressed in this project to improve our understanding of the recent dramatic reduction in Arctic sea-ice in the late boreal summer. For this purpose within the project **PASCAL** (Physical feedbacks of Arctic PBL, Seaice, Cloud And Aerosol; PS 106.1) the TROPOS-OCEANET and aerosol instrumentation on board of *Polarstern* will provide standard and additional spectral radiation measurements to determine the surface energy budget and a detailed characterization of surface, cloud and aerosol properties. Identical measurements are carried out from the AWIPEV Base (German – French Research Base) in Ny-Ålesund close to the open ocean while *Polarstern* will remain in the sea ice. The observations of both surface stations will be closely coordinated with collocated airborne activities of the Polar 5 and Polar 6 AWI aircraft operating between both stations along the gradient of sea ice concentration as well as close to *Polarstern*. These airborne observations will be supplemented by observations of the boundary layer structure (mean and turbulent quantities) from tethered balloon and several small Unmanned Airborne Vehicles UAV's, which will be operated during the ice station nearby *Polarstern*. In parallel with atmospheric studies, we will conduct oceanographic, physical and biological research on the drifting ice floe. Fig. 1.1 shows the planned overall cruise track.

Polar cod *Boreogadus saida* takes a key role in Arctic ecosystems, because it constitutes the staple food of seals and seabirds. Young polar cod live often associated with the underside of sea ice for foraging and protection from higher predators. Due to climate change, the extent of the under-ice habitat is decreasing. **SiPCA** (Survival of Polar Cod in a Chaning Arctic Ocean; PS 106.2) aims to investigate the importance of sea ice for polar cod in the Barents Sea and the adjacent Arctic Ocean. It is aimed to simultaneously sample the spatial distribution of polar cod, its prey, its predators and other environmental parameters using fishing nets and ocean sensors. The physical and biogeochemical properties of sea ice and melt ponds will be investigated during several sea ice stations. In a parallel research project, physical and chemical measurements of the atmosphere will be performed to investigate the vertical structure of the atmosphere and the energy budget of the ocean surface. At the end of the expedition, we aim to re-visit the ice floe of PS 106.1 to collect instruments left for continuous measurements. The data obtained from this expedition will help quantifying the carbon flux between sea ice, polar cod and endotherms, and estimate the susceptibility of polar cod to climate change. Scientific work will predominantly be conducted in ice-covered waters. Hence, the exact timing and geographic position of the research may deviate significantly from the planned cruise track, depending on sea ice distribution and concentration.

**TEMPO** (Temporal Evolution of Melt POnd characteristics in different Arctic sea ice) aims to fill the knowledge gap about the temporal and spatial dynamics of melt ponds and their role in the Arctic climate and ecosystem. Compared to field measurements, remote sensing techniques allow a more synoptic view of the Arctic sea ice; TEMPO therefore aims to develop a semi-automated application for monitoring melt pond characteristics via airborne and, in a second step, satellite data. Nevertheless, field data are inevitable for application development and accuracy assessment. To analyse temporal distribution and spatial evolution patterns of melt pond we therefore aim to establish a comprehensive set of both multi- and hyperspectral data and field data of melt pond properties (melt pond size, bathymetry, thickness of underlying ice, pond water constituents) and the reflectance behaviour of the surrounding sea ice.

**General statement concerning data management**

If not specified otherwise in the following sections, all data processing and quality control will be carried out in the individual home institutions. As soon as the data are available they will be accessible to other cruise participants and research partners on request. Depending on the finalization of academic theses and publications, data will be submitted to PANGAEA within 1-2 years.

# 2. PHYSICAL FEEDBACKS OF ARCTIC PBL, SEA ICE, CLOUD AND AEROSOL (PASCAL)

A. Macke, C. Barrientos, T. Conrath, U. Egerer, R. Engelmann, S. Fuchs, X. Gong, M. Hartmann, S. Kecorius, M. Merkel, M. van Pinxteren, M. Radenz, F. Rittmeister, K. Szodry, T. Vogl, A. Welti, J. Witthuhn, S. Zeppenfeld (TROPOS), M. Brückner, M. Gottschalk (LIM), M. Hieronymi (HZG), H. Kleta (DWD), U. Küster, T. Ruhtz (FU-Berlin), S. Schön, H. Schulz, M. Zanatta (AWI)

A. Wiedensohler (not on board)

**Objectives**

*a) Radiation & microwave remote sensing*

The net radiation budget at the surface is the driving force for most physical processes in the climate system. It is mainly determined by the complex spatial distribution of humidity, temperature and condensates in the atmosphere. The project aims at observing both the radiation budget and the state of the cloudy atmosphere as accurate as possible to provide realistic atmosphere-radiation relationships for use in climate models and in remote sensing. While similar experiments have been performed from land stations, only few data from measurements over ocean areas exist.

A multichannel microwave radiometer will be applied to continuously retrieve temperature and humidity profiles as well as cloud liquid water path over the ocean. Time series of these profiles will resolve small scale atmospheric structures as well as the effects of the mean state of the atmosphere and its variability on the co-located measurements of the downwelling shortwave and longwave radiation with different types of pyranometers (thermal and optical, fixed and gimbal-mounted) to allow intercomparison. The atmospheric profiles will be compared to and combined with METEOSAT SEVIRI products for a characterization of atmospheric state and radiative fluxes. Atmospheric aerosol optical thickness will be measured by means of hand held sun photometer and a multi-spectral solar radiometer, which also enables the determination of spectrally resolved aerosol and cloud radiative effects. Most instruments are integrated in the container-based atmosphere observatory.

*b) Lidar measurements*

Since more than 15 years TROPOS has developed and operated advanced lidar systems in order to study optical and microphysical aerosol properties in the troposphere. The system PollyXT, a semi-autonomous multiwavelength polarization Raman lidar will be operated inside a container, together with the radiation and microwave sensing equipment. The lidar is able to measure independently profiles of particle backscatter at three wavelengths and extinction at two wavelengths, which allows identifying particle type, size, and concentration. Additionally particle depolarisation is measured in order to discriminate between spherical and non-spherical particles, e.g. biomass-burning smoke vs. mineral dust or water clouds vs. ice clouds. The lidar is equipped with a measurement channel for atmospheric water-vapour, too. The data are used to characterize long-range transport of aerosol and identify pollution. The determined height-resolved aerosol extinction completes the radiation measurements. In this way, the radiative influence of single lofted aerosol or cloud layers can be calculated with radiation-transport models.

For the PS95 cruise the lidar will be equipped with a dual-wavelength near-range channel in order to observe the aerosol in the shallow marine boundary layer as well at 355 and 532 nm.

*c) Aerosol in-situ measurements*

The portfolio of the Aerosol Group at TROPOS includes the *in-situ* characterization of atmospheric aerosols in urban as well as remote background atmospheres, the characterization of regional and urban air quality, the examination of hygroscopic particle properties, the measurement and simulation of *in-situ* aerosol optical properties, the investigation of atmospheric transport processes, and the development of new and improved instruments for physical aerosol characterization. Onboard *Polarstern* all measurements will be conducted inside a temperature-controlled container laboratory, and focus on the particle characterization using high-end scientific instruments in order to study:

- physical aerosol properties using an Aerodynamic Sizer (APS) and Scanning Mobility Particle Sizer (SMPS) for particle number size distributions from 10 nm to 10 µm, and a Volatility and Humidifying Tandem Differential Mobility Particle Sizer (VH-TDMPS) for the hygroscopic growth of the particles;
- Optical properties using a nephelometer and an absorption photometer to measure the particle light scattering and absorption coefficients, respectively; and
- Particle chemical composition using a High Resolution Time of Flight Aerosol Mass Spectrometer (HR-ToF-AMS) for the non-refractory PM1.
- Cloud Condensation Nuclei (CCN) number size distribution and particle number size distribution to determine the particle hygroscopicity using a DMT CCN counter-100 and a Scanning Mobility Particle Sizer (SMPS)
- Ice Nucleating Particle (INP) number concentration using a DMT Spectrometer for Ice Nuclei (SPIN)

Additionally to the on-line instrumentations, a Digitel PM1 sampler will be installed on the roof of the aerosol container and will perform daily (from midnight to midnight) filter sample of the PM1 aerosol particles. The filters will be latter analyzed at the institute by a state-of-the-art analytical instrumentations to provide a precise identification of the organic chemical species.

Furthermore, black carbon measurements will be performed both on the ship and on the ice floe. Scientific goal is to understand atmospheric feedbacks of black carbon on snow and sea ice. This will be done by quantifying atmospheric black carbon presence and its properties close to surface of sea ice. Black carbon concentration, properties and absorption will be determined in the snow layer overlaying the sea ice. Snow properties will be monitored with an IceCube. The campaign will be the test bench for the freshly developed single particle soot photometer with extended range.

*d) Tethered balloon-borne measurements of energy budget of the cloudy atmospheric boundary layer in the central Arctic*

The quantification of the energy fluxes (turbulent fluxes of sensible and latent heat, momentum and radiative fluxes) within the Atmospheric Boundary Layer (ABL) in the central Arctic represents a key issue for an improved understanding of the Arctic response to Global Warming ("Arctic Amplification"), see Jeffries et al., (2012, 2013), Overland et al. (2012), Wendisch et al. (2017). The melting of Arctic sea ice is decisively linked with the surface energy fluxes. Surface sensible and latent turbulent heat fluxes are comparably low over sea ice and in this case the energy budget is dominated by the solar and terrestrial radiative fluxes, which are mostly influenced by the local cloud situation (e.g. Curry, 1986). If sea-ice is noticeably reduced, as observed within the past 20 years, the mean surface temperature increases and the typical low-level temperature inversion is weakened (lower stability). This would increase the turbulent energy fluxes in the Arctic ABL including the moisture flux, which would promote cloud formation.

Arctic low-level clouds exhibit several typical features compared to mid-latitude clouds, which cause important and specific effects (e.g., in terms of radiative transfer) and challenge the numerical modeling of Arctic low-level clouds. In particular, the often mixed-phase character of Arctic low-level clouds and the more complicated vertical structure of the ABL in the Arctic cause major issues compared to mid-latitudes. Arctic low-level clouds mostly warm the ABL. They are frequently organized in several distinct layers and the turbulent energy fluxes can be de-coupled from the surface fluxes (e.g. Shupe et al., 2013). Occasionally, moisture inversions coincide with the temperature inversion and the cloud layers penetrate the inversions, that is, the temperature inversion is not necessarily capping the cloud layer.

For an improved understanding of the cloudy ABL in the Arctic tethered balloon–borne measurements of turbulent and radiative energy fluxes are performed under different cloudy conditions and thermal stratification during the ice camp of this *Polarstern* cruise.

**Work at sea**

Upon departure from Bremerhaven both container-based atmosphere observatories will be installed at the deck of *Polarstern*. Most measurements will be performed underway and continuously. The following individual instruments are combined:

1. Multichannel microwave radiometer HATRPO. The instrument requires a calibration with liquid nitrogen at the port of Bremenhaven
2. Whole sky imager for cloud structure measurements
3. Multiwavelength polarization Raman lidar PollyXT
4. Handheld sun photometer (Microtops) for aerosol and cloud optical thickness
5. Standard meteorological data logging with extended radiation measurement equipment
6. Multispectral shadow-band radiometer
7. in-situ aerosol measurements
8. Measurement of cloud- and ice-nuclei concentration

9. Deployment of meteorological and oceanographic drifters and floats 8SVP and ARGO).
10. Regular calibration of SP2xr (black carbon measurements)

**Ice floe camp**

A two-week ice floe camp during the cruise is planned including tethered balloon observations. A 90 $m^3$-helium-filled balloon with a maximum payload of 8 kg will be deployed on the ice floe to profile the ABL from the ground up to 1500 m altitude. Several measurement units will be fixed at the balloon to study turbulent and radiative energy fluxes. Turbulence parameters will be measured alternatively with a lightweight hot-wire anemometer package and a three-dimensional ultrasonic anemometer. The balloon-borne energy flux measurements will be complemented by basic cloud microphysics observations and ground-based measurements of the energy budget at a small mast.

Since the maximum payload at the balloon has to be respected the entire available equipment cannot be used always. Thus different payloads will be combined during different launches according to the specific scientific question.

Furthermore, snow sampling and snow properties determination will be carried out in thwe context of black carbon measurements.

**Preliminary (expected) results**

1. 2d structure of the clear sky atmosphere and corresponding net radiation budget.
2. Horizontal structure of the cloud water path and its effect on the downwelling shortwave and longwave radiation
3. Vertical structure of temperature and humidity as well as its variability for validation of satellite products
4. Vertical profiles of tropospheric aerosols and their effect on radiation
5. Near-surface aerosol size distributions and their physical and chemical compositions

**Data management**

All final data will be stored at Pangea after post-processing and careful quality checks.

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# 3. WIND MEASUREMENTS USING A WIND LIDAR

S. Kohnemann (Uni-Trier)
G. Heinemann (Uni-Trier, not on board)

## Objectives

The representation of the atmospheric boundary layer (ABL) in the Arctic is a major challenge for numerical weather forecast models and regional climate models. Reference data sets are rare, particularly over the ocean areas. The group of the University of Trier will perform measurements of vertical and horizontal profiles of wind, turbulence and aerosols for the verification of a regional climate model (COSMO-CLM, Gutjahr et al. 2016) and for process studies.

## Work at sea

We will use a “Halo-Photonics Streamline“ wind lidar, which is a scanner and can operate with a maximum range of 10 km. The operation principle of the lidar is backscattering at aerosol particles and clouds and the use of the Doppler effect. The lidar operates at a wavelength of 1.5 µm with a pulse rate of 15 kHz and is eye-safe (class 1M). Values are typically averaged for 1 second. The used lidar is a programmable scanner, which enables vertical scans as well as range-height indicator (RHI) and horizontal scans. The RHI mode allows for measurements of e.g. convection structure over the ocean or the internal boundary layer at the sea ice edge. Radiosondes launched from *Polarstern* will be used for comparisons of the wind profiles (Heinemann and Zentek 2016).

## Preliminary (expected) results

The measurements during the *Polarstern* cruise shall yield a data set of continuous and high-resolution vertical profiles of wind and aerosol backscatter. Continuous sampling of vertical profiles will be performed during the cruise. For special observation periods (SOPs), RHI and horizontal scans will be performed yielding cross-sections of the ABL. The data will be used in a BMBF project for the verification of simulations using a high-resolution regional climate model.

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# 4. OCEAN COLOUR REMOTE SENSING: MEASUREMENTS OF WATER-LEAVING REFLECTANCE AND WATER CONSTITUENTS

M. Hieronymi (HZG), N. Oppelt (CAU), T. Ruhtz (FU-Berlin), P. Gege (DLR), A. Macke (TROPOS)

## Objectives

*a) Measurements of reflectance properties of the atmosphere-ocean interface*

Satellite remote sensing of ocean colour provides large-scale and global monitoring of the marine biomass and other water constituents. It is particularly suited for observations of remote and difficult accessible areas such as the North Atlantic and the Arctic Ocean. But, the higher the latitudes the more difficult is the atmospheric correction of the ocean colour signal, especially with the low sun elevation angle, the consequently longer path of radiance through the atmosphere, and increased reflectance at the sea surface. Reflectance (and transmittance) properties of the sea surface depend on the incidence angle of radiance and wind-dependent roughness of the surface, where the latter is even more important in the high-wind regions of the high latitudes. It is planned to measure the radiance distribution of sun and sky light in combination with underwater light field.

Currently there are large uncertainties in remote sensing of water constituents at high latitudes, as the sometimes large inconsistencies of different algorithms and directly measured quantities show. The differences are mostly caused by uncertainties of the optical properties of the water content, assumptions on scattering in the atmosphere and in the modeling of radiation transport. Further uncertainties arise from the specific difficulties of the conversion of weight or number density of water parameters into optical parameters. Central research to improve the results of model simulations and comparisons with measurements of high spectral resolution radiance spectra are their polarization properties and different measurement viewing geometries. In current models most optical effects of polarization are neglected. Salinity and temperature also have a non-negligible influence on the optical properties of water and its content. Therefore, one additional focus will be to study the degree of light field polarization. These measurements will be compared with theoretically determined polarized reflectance properties of the sea surface (Hieronymi, 2016), radiative transfer model simulations of FUB as well as with the water colour simulator WASI (Gege, 2004). The aim of this study is to provide a better sea surface reflectance factor, which is used to determine the water-leaving radiance and remote sensing reflectance, which in turn is basis for satellite remote sensing of ocean colour.

*b) Determination of optically-active water constituents*

The water colour is determined by spectral absorption and scattering properties of water constituents: pure sea water, phytoplankton, coloured dissolved organic matter (CDOM), and non-algae particles. Water samples from the upper mixed layer (<5 m) shall be collected and directly analysed in the laboratory. The aim is to determine the main quantities of ocean colour: inherent optical properties of the water samples as well as concentration of chlorophyll (biomass).

*c) Validation of Ocean Colour algorithms and match-ups with Sentinel-3/OLCI*

The remote sensing group at HZG is part of the Sentinel-3 validation team, and therefore aims to achieve match-ups with Sentinel-3/OLCI imagery with contemporaneous *in-situ* sampling. The first of a new satellite series Sentinel-3 (A) was launched early 2016; provisional ocean colour data are only available since October 2016. Real match-ups are difficult to accomplish; the scenery must be cloud free and the sampling must occur ±3 h of the satellite imagery. The expedition is interesting for validation purposes because of infrequent sampling in this sea area. Furthermore, chances of match-ups increase in higher latitudes since the polar-orbiting satellite passes the ship position up to six times per day. The Ocean and Land Colour Imager (OLCI) provides data with 300 m spatial resolution. Thus, there is a chance to observe areas between ice fields and study adjacency effects as well.

The radiometric measurements serve as validation of the atmospheric correction of OLCI scenery, i.e., the retrieved remote sensing reflectance (at the sea surface). The associated water sampling serves the validation of ocean colour retrievals, in particular the new neural network based algorithm ONNS by Hieronymi et al. (submitted December 2016). The final aim is to extend the exploitability of satellite imagery in high latitudes.

**Work at sea**

Different radiometers will be installed on deck of *Polarstern*, partly at the railing with free view to the sea surface. These measurements can be performed underway and during daytime continuously. However, the main objective is to employ a full set of instruments during stations of *Polarstern*, i.e., during transect towards the North as well as during stations close to the ice. This includes above and *in-water* measurements of the light field and water sampling, e.g. by means of a CTD. The following instruments will be deployed:

- different hyperspectral (UV, VIS, and NIR) radiometers (TriOS Ramses, SVC hr 1024i, Ibsen FREEDOM VIS) to measure irradiance and radiance,
- a polarimeter (URMS/AMSSP) for water (+ice, +atmosphere) to measure multi-angle polarized reflectance and radiance,
- a Pandora-2s system to derive atmospheric parameters (AOD, trace gases), and
- a Microtops II sun photometer (AOD)

Occasional water samples will be collected and analysed in the wet-laboratory on board. Laboratory works include:

- measurements of the particulate absorption using a PSICAM,
- filtration of water samples (filters will be deep frozen and stored for later analysis in the HZG lab), and
- measurements of CDOM absorption using PSICAM and LWCC.

Measurements from the OCEANET instrumentation will be used to characterize the atmosphere and sky radiance distribution.

**Expected results**

1. Hyperspectral radiance and irradiance data above- and in-water to characterize the available light and its angular distribution,
2. Vertical profile of the underwater light field.
3. Hyperspectral remote sensing reflectance,
4. Characterization of the sea surface reflectance factor as function of wind, waves, sun altitude, and atmospheric conditions,

5. Characterization of inherent optical water properties of water samples as well as concentrations of chlorophyll, total suspended matter, and CDOM.
6. Match-ups of *in-situ* sampling with Sentinel-3/OLCI imagery.

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# 5. MEASUREMENTS OF ATMOSPHERIC WATER VAPOR, AEROSOL AND THIN CLOUDS USING FT SPECTROSCOPY IN THE INFRARED

M. Palm, P. Richter, C. Weinzierl (Uni-Bremen),
J. Notholt (not on board), R. Basu (not on board)

**Objectives**

We will use mobile FTIR spectrometers onboard the *Polarstern* cruise PS 106 in the Arctic to study the geographical and temporal distribution of $H_2O$, HDO, thin clouds and aerosol in the Arctic. Together with the same suite of measurements at the AWIPEV research base in Ny-Ålesund, Spitsbergen the measurements will allow us to assess the representativity of the supersite in Ny -Ålesund for the Arctic.

*a) Measurements of columnar $H_2O$ and HDO*

Solar absorption spectroscopy in the infrared can be used to determine the distribution of many infrared trace gases in the atmosphere. In particular it is possible to measure the isotopic composition $H_2O$ in the troposphere. The isotopic ratio of $H_2O$ and HDO can be used to study the history of the air parcels sampled.

*b) Measurements of properties of aerosol layers and thin clouds*

Emission spectroscopy in the infrared can be used to study the composition of aerosols and properties of thin clouds. Since the self-emission of the the atmosphere is measured, those measurements are independent of an external light source like moon or sun.

**Work on board *Polarstern***

Prior the departure from Bremerhaven a container containing two mobile FTIR instruments will be installed onboard *Polarstern*. The measurements will be performed continuously during the cruse whenever weather conditions permit.

1. FTIR Spectrometer Bruker IFS 66. This instrument will be used to measure downwelling radiation in solar absorption mode. It requires clear sight to the sun during operation.

2. FTIR spectrometer Bruker IFS 28. It will be used to measure radiation emitted from the atmosphere. These measurements can also be performed during slightly couldy conditions

**Expected results**

1. Low resolution profiles of $H_2O$ and HDO and their ratio will be derived from the solar absorption measurements. A trajectory model will be used to track the path of the airparcels sensed.
2. The structure of radiation is analyzed to derive properties like the optical depth,the mean radius, and chemical composition of particles contained in clouds or aerosol layers.

# 6. PHYSICAL CHARACTERISTICS OF MELT PONDS (TEMPO)

N. Oppelt (CAU), G. Birnbaum (AWI), P. Gege (DLR), M. König (CAU), N. Fuchs (AWI)

**Objectives**

Improving the predictive capabilities for the development of Arctic sea ice cover strongly depends on a better understanding of the ice-albedo feedback mechanism. There is still a lack of knowledge about the temporal and spatial dynamics of melt ponds and their role in the Arctic climate and ecosystem. Using a combination of multi- and hyperspectral airborne imagery, field spectroscopy and bio-optical modelling we aim to quantify melt pond fraction, melt pond depth, thickness of underlying ice, pond water constituents (chlorophyll, suspended organic and inorganic matter) and surface albedo in different ice regimes. The main goal is to develop a semi-automated application for melt pond analysis for airborne hyperspectral instruments. A further goal is to employ the collected data to validate and improve parameterizations of melt pond properties used in regional and global climate models. Availability of suitable data is crucial for algorithm and parameterization development and their validation. We therefore aim to establish a comprehensive set of airborne multi- and hyperspectral data to investigate diurnal and intra-seasonal melt pond dynamics and the surrounding ice. Ground based measurements of pond characteristics such as pond depth, thickness of underlying ice, pond bottom characteristics as well as optical properties of the pond water and the surrounding sea ice surface accompany airborne data acquisition. The ground based measurements are essential for the parameterization of bio-optical models as well as for the validation of the results, which is crucial for accuracy assessment.

**Work at sea**

*a) Airborne acquisition of sea ice and melt pond characteristics*

Airborne measurements will be carried out by use of a helicopter. Two instruments will be mounted at the helicopter, a Canon DSLR camera and an $AISA_{eagle}$ hyperspectral camera. To couple ground based and airborne measurements, the flight pattern should include several overflights of the sampling areas. Helicopter flights should also be carried out when the ship is steaming between two ice stations. In this case the overflight of a sampling area can be omitted, so the focus is on spatial variability of pond characteristics. To correct for ice drift, stable targets (e.g. fixed measurement equipment) at each ice station will be used.

As long as no melt ponds form, airborne measurements will focus on pattern which allow for the derivation of the directional reflectance behaviour of sea ice surfaces.

Measurements from the OCEANET and TROPOS instrumentation will be used to characterize the atmosphere and sky radiance distribution.

*b) Measurements of melt pond characteristics*

Optical properties of open ponds are determined using measurements of absorption from water samples (PSICAM), and radiance and irradiance measurements of submersible radiometers (TRIOS) above and under the water surface. Whenever possible, horizontal and vertical profiles will be measured to characterize surface reflectance as a function of bottom depth and the underwater light field as a function of sensor depth. For shallow ponds optical properties will be determined using field spectrometer (ASD, SVC and Ibsen). The largest uncertainty for deriving water depth is expected from the pond bottom, whose ice can lead to strong anisotropy that are missing in other water types and hence are not yet accounted for in models. To determine the influence of the pond bottom on above-water observations and to obtain spectral data of pond bottom reflectance, we aim to measure at different water depths pond reflectance with and without plastic foils covering the pond bottom. The water will be removed from some small ponds to measure the spectral and angular reflectance properties in air.

To determine near-surface broadband up- and downwelling irradiances a radiation rack with ventilated short- and longwave radiation sensors mounted on a Nansen-sledge and a mobile tripod with a net radiometer will be operated over melt ponds and sea ice surfaces.

For shallow water pond depth will be measured along profiles using levelling bars. If pond depths are higher than 30 cm an echo-sounder (EvoLogics, Sonobot) is used to provide spatial information of pond depth and pond bottom relief.

*c) Determination of optically-active water constituents*

Optically active water constituents (chlorophyll, suspended organic and inorganic matter) are determined in the lab using water samples taken during ice station. The aim is to determine the main optical properties of melt ponds: inherent optical properties of the water samples as well as concentrations of chlorophyll (biomass), total suspended matter, and coloured dissolved organic matter (CDOM). Chlorophyll concentrations will additionally be deduced via fluorescence measurements using an algae torch.

*d) Determination of reflectance properties of surrounding sea ice surfaces*

The Arctic environment shows high contrasts between water surfaces with relatively low reflectance and neighbouring areas of high reflecting ice and snow. To consider adjacency effects in remote sensing observations, ice and snow covered areas neighbouring the melt ponds will be measured using different types of field spectrometer (SVC and ASD, 350 – 2,500 nm, spectral resolution approx. 3 / 9 nm; Ibsen 350 – 850 nm, spectral resolution approx. 2 nm).

To analyse the bi-directional reflectance properties of sea ice one of the field spectrometers will be attached to an angular measurement device. Measurements strongly depend on illuminations conditions, but we aim to measure at least at 5 different angles.

In summary, we will use the following instruments for ground-based measurements:

- Ramses hyperspectral radiometers (TriOS) to measure irradiance and radiance at deep pond water,

- ASD, SVC and Ibsen field spectrometers to measure reflectance properties of sea ice surfaces and reflectance of shallow ponds,
- Kipp&Zonen CM22 pyranometers and CGR4 pyrgeometers and additionally a Kipp&Zonen CNR4 net radiometer to measure broadband short- and longwave irradiances,
- Sonobot to measure pond depth and bottom relief of deep ponds,
- Levelling bars to measures pond depth (shallow ponds),
- Algae torch to measure chlorophyll fluorescence
- GPS to measure sampling locations as well as pond size/shape measured with levelling bars

Water samples will be collected at different melt ponds and analyzed in the wet-laboratory on board. Laboratory works include:

- Measurements of the particulate absorption using a PSICAM,
- Filtration of water samples (filters will be deep frozen and stored for later analysis), and
- Measurements of CDOM absorption.

Snow and ice sampling will be performed in collaboration with the PASCAL and SIPCA groups. Measurements from the OCEANET and TROPOS instrumentation will be used to characterize the atmosphere and sky radiance distribution.

At days without airborne acquisitions we conduct ice and snow measurements with the field spectrometers with special emphasis on directional reflectance behaviour of pond bottom and ice surfaces. The same applies for no-ponds conditions.

**Expected results**

The measurements are expected to provide:

1. For shallow ponds linear profiles of pond depth and size; for deep ponds spatially high-resolution pond depth profiles;
2. Hyperspectral radiance and irradiance data above- and in-water to characterize the available light and its angular distribution under water;
3. Horizontal and vertical profiles of the underwater light field of deep ponds;
4. Hyperspectral remote sensing reflectance of deep and shallow ponds with reference measurements of snow and ice;
5. Spectral and angular properties of pond bottom reflectance;
6. Inherent optical water properties of water samples as well as concentrations of chlorophyll, organic and inorganic matter;
7. Match-ups of *in-situ* sampling with AISA, Sentinel-2 and -3 overpasses;
8. Characterization of ponded sea ice surface for atmospheric correction of airborne data;
9. Maps of pond fraction, pond depth, thickness of underlying ice as well as sea ice and pond albedo from airborne data;
10. Measurements will be used to develop remote sensing algorithms for long-term monitoring of melt pond depth, thickness of underlying ice and content of organic and inorganic substances;
11. Measurements will be further used to validate and improve parameterizations of melt pond properties used in regional and global climate models.

**Data management**

All oceanographic data collected during PS 106.1 and PS 106.2 will be delivered to the PANGAEA database and to the appropriate national data centres after post-cruise calibration and processing.

# 7. UAV MEASUREMENTS DURING *POLARSTERN* CRUISE PS106.1 TO THE ARCTIC IN MAY/JUNE 2017

P. Tissler (FMI), M. Jonassen (UNIS), C. Lüpkes (not an board)

**Objectives**

This project aims to obtain data about the structure of the Arctic atmospheric boundary layer (ABL) over sea ice during late spring. Airborne observations will be carried out with two unmanned air vehicles (UAV) that have been used successfully already during an Antarctic cruise with RV *Polarstern* (ANT XXIX/6) (Jonassen et al. 2015), and one new UAV system.

The project (measurement and data analysis) consists of joint work by groups from the Finnish Meteorological Institute in Helsinki (FMI), the University Centre in Svalbard (UNIS) and by the Alfred Wegener Institute in Bremerhaven. It is based on the operation of two UAVs from UNIS; a fixed wing SUMO system and a new quadrocopter BEBOP 2 system in addition to a small quadrocopter owned by FMI. The data from these airborne instruments supplement the other measurements in the atmospheric boundary layer during PASCAL but especially the balloon-borne measurements of mean meteorological variables by TROPOS.

Based on the profiles of mean quantities (wind, temperature), which will be obtained by the UAVs, the structure of the atmospheric boundary layer during the drift station will be characterized and compared also with airborne measurements by Polar 5 and 6 (campaign ACLOUD) obtained during the same period as a part of the DFG funded Arctic Amplification project.

**Work at sea**

Work at sea is restricted to the operation of the UAVs during the ice stations. The coordinated flight patterns will depend on both meteorological conditions and on the sea ice situation. Although the main focus is on vertical profiling in case of inhomogeneous sea ice cover (e.g. due to imhomogeneous melt pond distribution) also the horizontal variability of atmospheric parameters at constant flight heights will be considered in a radius of about 2 km around the ship by SUMO. Thereby, the actual flight levels will depend on the ABL depth, which will be estimated roughly prior to the flights from the last available *Polarstern* sounding or balloon based profile. The SUMO aircraft will be operated below 3,000 m height, quadrocopter flights will be below 100 m and the latter is used only for vertical profiling.

**Expected results**

We expect to obtain a unique and high-quality dataset about the vertical structure of the ABL over the Arctic sea ice and especially with respect to the temporal development of the ABL since previous measurements are available mostly from aircraft or soundings which cannot investigate the evolution in high temporal resolution. Together with the other meteorological measurements during PASCAL the new data set will allow increasing our knowledge on the Arctic climate system and especially on the role of clouds for the ABL structure. Data can be used later for e.g. the validation of operational weather prediction models.

**Reference**

Jonassen M.O., Tisler P., Altstädter B., Scholtz A., Vihma T., Lampert A., König-Langlo G., Lüpkes, C. (2015) Application of remotely piloted aircraft systems in observing the atmospheric boundary layer over Antarctic sea ice in winter

# 8. PHYSICAL OCEANOGRAPHY

A. Nikolopoulos (ABWR), T. Linders (UGOT), C. Heuzé, E. Andrée, S. Sahlin (UGOT)

**Objectives**

The physical oceanography (PO) component of PS106 aims to map the physical water properties temperature, salinity, and water velocities of the study region, with a focus on describing the prevailing conditions connected to the objectives of SiPCA.

In this sector of the Arctic Ocean, the dominant hydrographic feature is the Atlantic water (AW) inflow from the Nordic Seas by the West Spitsbergen Current and the Fram Strait inflow branch. The Fram Strait branch is estimated to carry the bulk of the oceanic sensible heat into the Arctic Ocean. The dynamics of this heat-bringing boundary current, and contribution of warm subsurface waters to the ice reduction, are still not fully understood and further efforts are required to understand the oceanic heat fluxes - in particular during the transition seasons when sea ice melts or forms. The Arctic Ocean currently progresses towards a seasonally sea-ice free ocean with several record-low ice extents within the last few years, out of which the second lowest extent was observed in autumn 2016 (NSIDC, 2016). The seasonal ice retreat occurs in the season of maximum biological productivity and is hence of special interest for biology, oceanography and sea ice dynamics.

The oceanographic objectives include collecting detailed information on the properties of the boundary current in two transects across the continental slope north of Svalbard. Also, measurements will be undertaken of turbulent velocities and the vertical distribution and composition of particles under the sea ice. Work at sea

The PO team will work with instrumentation both from the ship and the ice. Recurrent measurements of the general hydrographic (Conductivity/Temperature/Depth) conditions will be carried out from the ship with the ship-CTD/Rosette, equipped with additional sensors for Chlorophyll, Oxygen and Turbidity, a lowered Acoustic Doppler Current Profilers (ADCP), and 24 12L-Niskin water sampling bottles. Measurements may also be done with Expendable CTDs (XCTD), in order to refine the hydrographic profiling in time or space.

During the drift phase of PS106.1, a top-anchored mooring line will be deployed through the ice equipped with ADCPs and CTDs for measurements of the particle distribution and the general velocity field in the upper 200 m of the water column (Fig. 8.1). The mooring line will stay in the water during the entire drift period in order to collect data for as many days as possible. A Laser *In-situ* Scattering and Transmissometry (LISST) particle size analyser will be used on, or close to, the mooring line in order to measure the distribution of particles of 2.5 - 500 µm size. The LISST can also be mounted on the ship-CTD/Rosette in order to complement these profiles (down to maximum 300 m).

The second cruise leg PS106.2 is planned along transects stretching from the relatively shallow continental shelf area and northward into the deep Nansen basin (Fig. 8.2). Along these transects physical and biogeochemical measurements and sampling will continuously take place around the clock. The PO-BGC team will mainly acquire data by the ship-CTD/Rosette and XCTDs. During ship-CTD casts down to maximum 300 m the LISST will also be used recurrently. While over the shelf slope, transient tracer samples will additionally be taken for age analysis of the AW. Also, two lines of LoTUS and T-pop bottom landers will be deployed at ~800 m and ~1,200 m depth on the slope (see Fig. 8.2). These are expendable temperature sensors that take measurements at the bottom of the ocean every 30 minutes for two years. At the end of their measurement period, the landers will ascend automatically to the surface and send off their data by satellite.

Due to the small size of each working group (both cruise legs), the PO-team will closely collaborate with the Biogeochemistry team (BGC). PO may therefore also take on tasks such as snow and ice coring, and the subsequent handling of the collected water/snow/ice samples in the ship labs.

**Expected results**

The PO measurements will provide information on the oceanographic conditions during a time of the year for which we still, in general, have relatively little data.

The mooring line is deployed for investigating the general velocity field under the ice (approx. 0-200 m depth), but also the particle and zooplankton composition. By processing the recorded ADCP data into sound scattering layers the aim is to gain information of the daily vertical migration patterns of zooplankton and their correlation to hydrography, light conditions and phytoplankton distribution. Analysis of recurrent eDNA samples taken at the mooring location, and data from other working groups (nets and sediment trap etc.) will help identify the species present. The top-most ADCP on the mooring (Fig. 8.1) will measure turbulent velocities in the layer just beneath the ice and provide information on the vertical exchanges.

The data provided by the LISST will help decipher the type and quantity of particles seen in the upper 300 m of the water column, both in association with the mooring line measurements and during the transit between shallow shelf areas and the deeper basin.

Analysis of transient tracer samples will give the age of the AW, that is, its formation year in the North Atlantic. These results will be compared to other measurements that have been taken further upstream in Fram Strait in order to infer where the AW is exactly coming from, and how long it takes to move around the Arctic. The aim is also to assess the feasibility of such measurements, which traditionally are not performed by the PO team.

The technical aim of the bottom landers deployment is to compare the performance of the two sensor types in order to decide which lander to use on larger scale in future expeditions; the T-pops developed by the University of Rhode Island and the LoTUS developed by KTH Royal Institute of Technology in Stockholm. The scientific aim is to measure the high frequency variability of the temperature of the AW over a long period of time, for a fraction of the cost of a traditional mooring. Hence we will assess what controls the day-to-day, seasonal and longer term amount of heat that enters the Arctic, critical for the fate of the Arctic sea ice.

**Data management**

The oceanographic data collected during PS106 will be delivered to the PANGEA database and to the appropriate national data centres after post-cruise calibration and processing.

**References**

NSIDC (2016) National Snow and Ice Data Center, Arctic sea ice news and analysis, http://nsidc.org/arcticseaicenews//

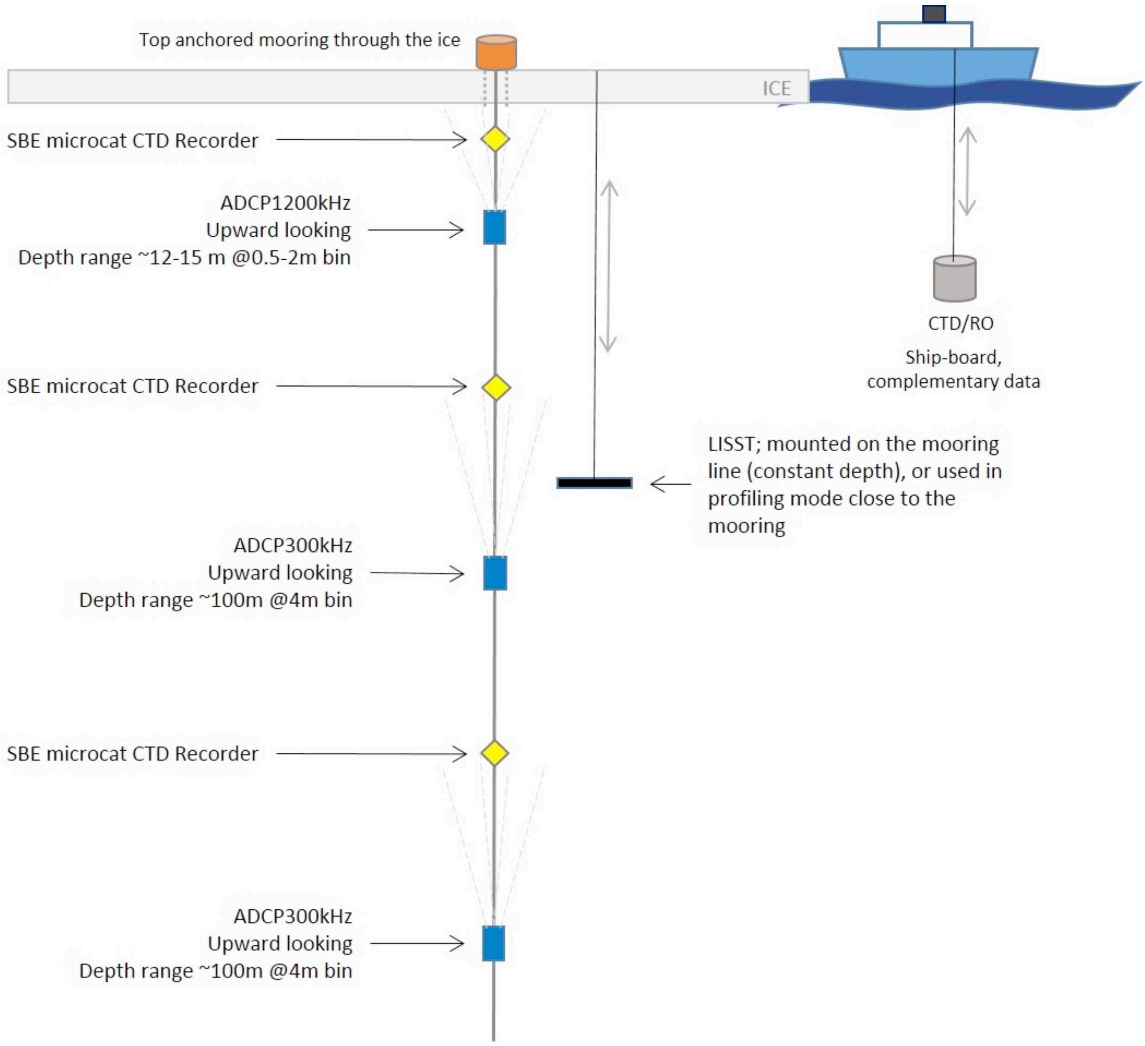


*Fig. 8.1: Sketch of the top-anchored mooring line to be deployed through the ice and left in as long as possible during the drifting phase (PS106.1). The total depth range of the mooring is approx. 200 m.*

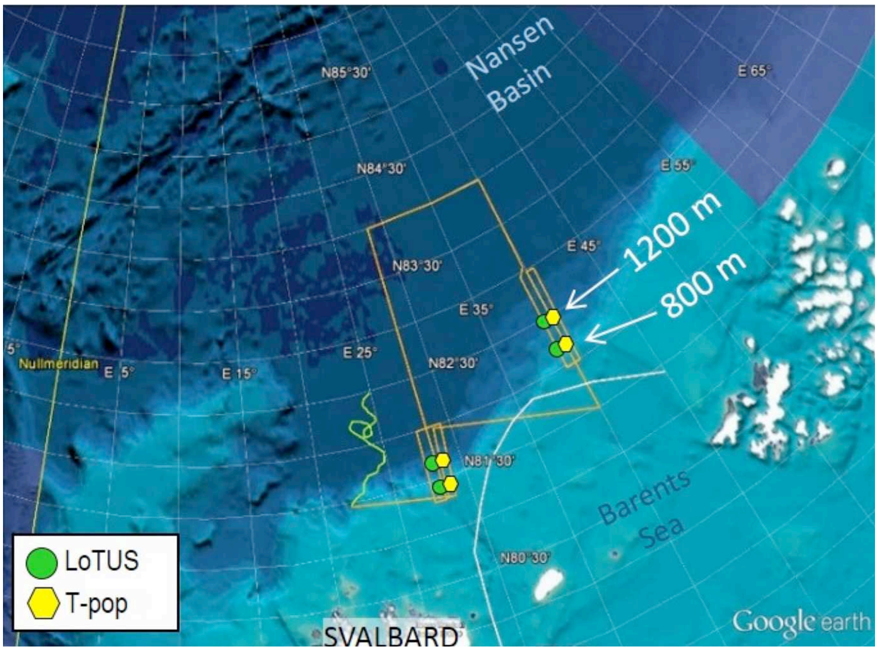


*Fig. 8.2: The deployment strategy during PS106.2 for the bottom landers (yellow and green symbols). Both types of landers will be deployed on the continental shelf slope at two different depths (approx. 800 m and 1,200 m).*

# 9. SEA ICE PHYSICS

M. Nicolaus, V. Coppolaro, C. Katlein, L. Tiemann, A. Sommerfeld (AWI)

## Objectives

The observed shift from thicker multi-year to thinner first-year sea ice in the Arctic has consequences for various physical and biological processes within the sea ice and the upper ocean layer. For example, thin ponded sea ice transmits a significantly higher portion of the incoming solar radiation than snow covered thick ice. Hence, the optical properties of sea ice determine the amount of light (energy) that is transmitted into the ice and further into the upper ocean, contributing to warming and melting of sea ice. In addition, the amount of solar radiation dominates primary production and other biological processes in and below the ice layer. Following up observations during earlier cruises, we want to quantify the amount of light transmitted through sea ice during the melting season as a function of snow, sea ice, and upper ocean properties. This time of year coincides with the highest radiative fluxes and the onset of in and under-ice biological productivity. However, a significant lack of data exists in this transition season, so that this expedition provides a great opportunity to measure the changing physical properties of the ice and the evolution of its surface geometry as snow and sea ice start melting. At the same time, the sea ice mass budget is very sensitive to small changes in the energy budget and dominant processes. Snow melt, melt pond formation, sea ice melt, and ocean surface freshening have strong feedbacks with energy fluxes. These fluxes are directly related to the geometry of sea ice, which exhibits large variation on all scales. The geometric variation can be described in terms of distributions for key variables:

for ice thickness, snow thickness, floe size, leads, and ice ridges. These are needed especially in sub grid scale, the length scale shorter than the resolution of Arctic ice drift models. Hence the main aim is to quantify these properties and the resulting fluxes as time series representing the floe-scale spatial variation.

An additional source of information regarding the state of the Arctic sea ice and its snow cover is visual classification of key sea ice variables by sea ice observers. Though quite subjective, visual observations have the promise of creating large datasets due to the numbers of vessels in the summer Arctic. Such datasets are of high value to record the ice conditions during various observations during the cruise and for validation of remote sensing products.

Another objective of the long drifting station during the first cruise leg is to test workflows, team coordination, and equipment tests for set ups on long-lasting sea ice stations. This involves experience in avoiding and handling of human influences on measurements and effective logistics needed for the yearlong MOSAiC expedition in 2019/20. Advancing observational capabilities in sea ice studies requires ongoing technical developments of measurement platforms and instruments as well as obtaining expertise in new measurements and inter-calibration of methods. Various advances have been made and further steps are necessary towards MOSAiC. Hence, one aim is to test and quantify new methods and instruments, also in the framework of the FRAM and ACOSS infrastructure programs.

**Work at sea**

The main work of the sea ice physics group on both legs is the operation of the new under ice ROV system BEAST. This work will be performed in close collaboration with other partners of the SIPCA (Survival of Polar Cod in a Changing Arctic Ocean) group. During PS106.1 these observations will be conducted, e.g. every second day on the drifting station, while on PS106.2 the work will continue during regular ice stations, where the ice is accessed either by gangway or helicopter. The main sensor suite of the ROV is designed to obtain spectral light transmission through snow and sea ice, to acquire sea ice geometry using a multi-beam sonar and measure oceanographic and biological properties of the underlying water column. Additional new developments of net hauls and water sampling will be tested in direct relation to the sampling and measurement programme from *Polarstern*. In conjunction with the measurements from the ROV, sensor calibrations and inter-comparisons will be performed, using the well known standards on board the vessel.

Sea ice and snow properties will be measured along transects over the floe and on designated sampling sites. These measurements will not only complement the ROV observations from under the ice, but also extend beyond these measurements. Similar to the ROV measurements during PS106.1 these observations will be conducted, e.g. every second day on the drifting station, while on PS106.2 the work will continue during regular ice stations. Main instruments are Magna Probe soundings for snow depth and a GEM-2 electromagnetic induction device for total ice thickness sensor along selected survey lines. Additional measurements with a terrestrial laser scanner and helicopter borne aerial photography of the surface are planned to observe snow cover and melt pond changes over the melting season for the floe area. Snow and ice sampling will be performed in collaboration with the PASCAL and SIPCA groups. In particular, snow studies are directly coordinated with their surface and airborne measurements and sampling focusing on surface albedo and the role of impurities and aerosols. Sea ice thickness measurements are complemented by airborne transects using the EM-Bird technology during PS106.2, if weather conditions allow regional (e.g. 60 nm) transects.

Several autonomous measurement devices will be installed on the main floe of PS106.1 as early as possible and be recovered at the end of PS106.2. These instruments will measure sea ice mass and energy budgets (e.g. Ice Mass-balance Buoys), snow depth (e.g. Snow Buoys), weather conditions (e.g. Autonomous Weather Stations), spectral solar radiation above and under sea ice, and surface photography. These instruments are maintained as long as the station is manned, but measurements continue fully autonomously afterwards. These autonomous measurements will hence connect the other observations and measurements between both legs and provide continuous measurements of snow and ice conditions over most of the melt season. For eased recovery of the autonomous stations at the end of PS106.2 the coordinates of the drifters will be fed in near-real time to the Ice-GIS system on board of *Polarstern*. Developing these deployment and recovery routines are essential elements of the work during PS106.

Continuous observations of the sea ice conditions shall be made while the ship is moving with hourly observations of sea ice conditions by trained observers from the bridge (every six hours during drift periods).

**Preliminary (expected) results**

Over all, the collected data shall lead to a better understanding of the seasonal evolution of Arctic sea ice, in particular during springtime, when the icescape melts and starts to be covered by melt-ponds causing a sudden change in the physical properties of the ice pack.

The spectral radiation measurements (together with their meta data and complementary data sets) will help to fill the observational gap of such data for the main melting period when uncertainties are currently highest. These measurements will allow insights into the vertical and horizontal distribution of energy fluxes though summer sea ice in direct relation to habitat properties and ecosystem functions (cooperation in SIPCA).

The transect data of snow depth and sea ice thickness will also contribute to similar measurements during earlier campaigns in similar regions and/or times. This will allow comparisons of the 2017 conditions to other years. In addition, these mass- and energy balance data will be directly linked to the other observations. Since the sea ice is an integrator of atmospheric and oceanographic heat fluxes, the data sets will help to interpret these data and lead to a more general understanding of dominant processes at different times or under specific conditions.

The time series from the (mainly) autonomous instruments will help to describe and quantify the progress of the melt season. These data sets are most likely important background data sets for other studies and will help to close observational gaps during this time of the year, which is much less studied than the later summer into freeze up.

**Data management**

All data from the radiation measurements and the ROV require post-processing after the cruise and are fed into the AWI data-portal via the Raw-Data-Ingest framework. The data from AWI sensors will be made publically available in the PANGAEA database within one year. Visual sea ice observation data will be distributed by a standardized database at the International Arctic Research Center, University of Alaska, Fairbanks, and will be made available through PANGEA. All measurements from autonomous devices are available in near-real time through Meereisportal.de and are archived after quality control to PANGAEA.

# 10. NITROGEN CYCLING AND MICROBIAL ECOLOGY IN THE ARCTIC OCEAN

A.A. Fong, E. Raes, S. Spahic (not on board), A.M. Waite (not on board) (all AWI)

### Objectives

Plankton community composition and primary productivity are controlled by a combination of environmental conditions and biological interactions. In the Arctic Ocean, light availability is considered a major control on primary productivity due in part to variations in sea ice extent and thickness. Nutrient availability is also a critical control on primary productivity and can shape plankton community composition. Nitrogen compounds, such as nitrate and ammonium are readily assimilated by both photosynthetic and heterotrophic microscopic plankton. Therefore, assimilation rates and fluxes of nitrogen compounds, and in turn carbon, are important to quantify with regard to their control on primary productivity and shaping plankton communities.

In more recent years, dinitrogen fixation has been observed as another mechanism by which plankton communities could meet their nitrogen demand. However, this process is limited to specific groups of microbes containing nitrogenase genes. The process of biological dinitrogen fixation is the conversion of dinitrogen gas to ammonia. Dinitrogen fixation is an energetically expensive process and iron is required in nitrogenase enzyme complex. Classically, biological dinitrogen fixation is believed to be limited to subtropical and tropical regions of the worlds' oceans, with waters warmer than 25°C and depleted in inorganic nitrogen, such as nitrate. Recent work has shown a greater geographical extent and more diverse nifH phylogeny than previously believed with low, but measureable rates of dinitrogen fixation and recovery of nifH genes from polar regions.

Our aim is to examine the temporal evolution of nitrogen utilization in an ice-covered region of the Arctic Ocean. We plan to use a combination of observations and experiments to quantify nitrogen assimilation rates, dinitrogen fixation rates, and identify key players in these nitrogen and carbon transformation process. We will also characterize the planktonic community through a variety of independent methods, including HPLC pigment biomarkers, light microscopy, and phylogenetic analyses. We will combine biogeochemical and ecological measurements of planktonic biomass and composition with experimental rate measurements and molecular analyses of microbial assemblages and their functional diversity. Together, these measurements will provide both a mechanistic and more comprehensive understanding of nitrogen and carbon cycling processes in the Arctic Ocean.

### Work at sea

Discrete water column samples from Niskin bottles attached to the main CTD-rosette will be collected from 4-8 depths. Depths of interest span both the upper ocean and mesopelagic. A suite of biogeochemical parameters will be measured from samples collected throughout the water column. Plankton community composition will be assessed by HPLC pigment biomarker analysis, light microscopy, and for smaller organisms, flow cytometry. Small volume water volume samples for cell enumeration via flow cytometry will be collected and archived. Also, samples for 13C and 15N natural abundance, and particulate carbon and nitrogen concentration will be collected to determine the isotopic signatures and elemental composition of suspended organic matter. Additionally, nucleic acids (DNA and RNA) will be collected by positive pressure filtration for gene surveys, including but not limited to surveys of 16S rRNA genes (microbial diversity) and *nif*H genes (nitrogenase).

Nitrogen and carbon stable isotope tracer incubation experiments will be conducted with dual spiking of 15N-Nx- and 13C-C-labeled compounds into natural seawater. These additions allow us to calculate nitrogen assimilation and fixation rates and estimate primary production rates. Experimental samples will be shaded with neutral density screening and either incubated in on-deck incubators plumbed with surface seawater or *in-situ* on a mooring line tethered to the ice.

**Expected Results**

We expect to resolve the temporal evolution of nitrogen utilization rates by planktonic microorganisms in ice-covered oceanic waters during the late Arctic spring. Our sampling is expected to result in concurrent measurements of inorganic dissolved nitrogen assimilation rates, coupled to functional gene expression patterns of specific nitrogen transformation processes. Additionally, we intend to characterize the functional diversity of marine microbial assemblages to inform how shifts in community composition affect carbon and nitrogen transformations. A majority of samples will be analysed at the onshore laboratory. Rates, expression patterns, and assemblage composition will be analysed in the context of hydrographic and biogeochemical data.

**Data management**

Cruise participants and research partners can obtain data upon request. All biogeochemical and ecological data will be archived on Pangaea following quality control and assurance. Sequence data will be archived in an open access public database, either ENA or GenBank.

# 11. PROTISTIAN PLANKTON, BIOGEOCHEMISTRY AND VERTICAL PARTICLE FLUX (FRAM/ PEBCAO GROUP)

A. Stecher, P. Sprong, B. Staufenbiel, K. Metfies (not on board), E.-M. Nöthig (not on board) (all AWI)

**Objectives**

The Arctic Ocean is strongly affected by climate change, which in turn will have large impact on the carbon cycle and sequestering in the pelagic ecosystems. Long-term observations of all plankton size classes, from pico- to large zooplankton, as well as routine measurements of biogeochemical plankton parameters are thus required to understand and predict future ecosystem functioning.

Since the nineties, ecological investigations of unicellular phyto- and protozooplankton biomass, species composition, productivity, sedimentation and biochemical parameters (i.e. chlorophyll *a*, particulate organic carbon (POC) & nitrogen, carbonate and biogenic silica) have been carried out in Arctic waters of the central Arctic Ocean (CAO) during 9 cruises between 1993 and 2016 with *Polarstern*. Whereas phytoplankton biomass, chlorophyll *a* (integrated values 0 -100 m), stayed more or less constant in the CAO during late summer cruises, POC distribution patterns for the summertime show slightly different results with a slightly increasing trend other than chlorophyll *a*. Flux rates of POC where at least one order of magnitude lower in CAO than in eastern Fram Strait at the LTER HAUSGARTEN site. Whereas in the CAO ice algae dominate the recognizable flux fraction, fecal material prevailed in eastern Fram Strait traps, pointing towards different systems of organic matter production and modification.

Our work on planktonic protists and biogeochemical fluxes will also focus on monitoring species and biomass distribution, on biogeochemical parameters and on the vertical particle flux of organic matter in relation to season, sea ice cover, nutrient distribution and water circulation patterns. Furthermore, metatranscriptomic analyses will help to give insides into community functioning. Specific hypotheses we intend to test are:

- Shifts in species compositions on different trophic levels will change trophic interactions and change fluxes and export of organic matter.
- Changes in the circulation like the stronger influence of Atlantic water masses may also alter the pelagic system and export fluxes.

**Work at sea**

*Biogeochemical & biological parameters from rosette samples*

We will sample seawater (1-10 L, depending on parameters sampled) with a CTD/rosette sampler at 5-10 depths. Additionally we will sample Arctic seawater using a newly developed automated filtration (AUTOFIM) device that is coupled to the ships pump. All samples except those for phytoplankton & protozooplankton counts will be filtered and preserved or frozen at -20°C and partly at -80°C (RNA, HPLC) for further analyses. At the home laboratory at AWI we will determine the following parameters to describe the biogeochemistry and the abundance and distribution of protists: Chlorophyll *a* concentration, particulate organic carbon (POC), particulate biogenic silica (PbSi), phytoplankton & protozooplankton abundance (traditional microscopy, molecular-biological assessments of protist communities) and community structure (metatranscriptomes).

*Sediment trap deployment*

If the ice situation allows, short-term moorings with small sediment traps (Hydrobios, equipped with an automatic system to collect 6 samples per selected sampling period) will be attached to ice floes. This work will be carried out together with sea ice physicists. Traps will be exchanged within 1 to 4 weeks according to the given the ice situation. Together with previous flux studies this will yield in a time series studying sedimentation events in the Arctic Ocean.

**Preliminary (expected) result**

We expect similar results including trends like we observed during the other years of our time-series investigations. Results will strongly depend on the physical and chemical environmental settings in the field.

**Data management**

Many of the samples (i.e. pigment analyses, particulate matter in the water column, etc.) will be analysed at AWI within about two years after the cruise. Data will be made available to the public via PANGAEA after publishing 2 to 5 years after the cruise.

# 12. SEA ICE BIOLOGY AND BIOGEOCHEMISTRY

I. Peeken (AWI), G. Castellani (AWI), H. Flores (AWI, UHH), J. Ehrlich (AWI, UHH), B. Lange (AWI), D. Kohlbach (AWI, not on board), M. Graeve (AWI, not on board), F.L. Schaafsma (Wageningen Marine Research), R. Gradinger (UiT), B. Bluhm (UiT, not on board), B. Hassett (UiT), E. Kunisch (UiT), E. Damm (AWI), J. Verdugo (AWI)

### Objectives

Sea ice is of major importance in the polar oceans since it affects the solar radiation fluxes due to its reflective properties, and constitutes a habitat and feeding ground for various organisms of the polar ecosystem. The Arctic Ocean is now in a state of rapid transition that is best exemplified by the marked reduction in age, thickness and extent of the sea ice cover. The European Arctic margin is largely influenced by drift ice formed on the Siberian shelves and carried to the Fram Strait via the Transpolar Drift. Sea ice thickness for the various regions of the Transpolar Drift between 1991 and 2007 showed a reduction in modal ice thickness from 2.5 m towards 0.9 m. A long-term trend towards thinner sea ice has profound implications for the timing and position of the Seasonal Sea Ice Zone, and the anticipated ice free summers in the future will have major implications for the entire ecosystem and thus alter current biogeochemical cycles in the Arctic.

Due to the generally low solar elevation and extreme seasonality, light is considered to be the key factor for primary production in the ice covered oceans. Light penetration in the Arctic is generally reduced by the sea ice cover, and additionally snow greatly reduces light transmission through the ice. In the framework of climate warming, the atmospheric moisture budget in the Arctic is forecast to change, resulting in an increasing snow cover and thus reducing the light for primary production. However, the reduction from MYI to seasonal ice and additional increase of melt ponds on FYI will substantially increase light transmission through ice. Additionally, the sea-ice surface topography, i.e. the presence of deformation elements (ridges) and melt ponds, determine the redistribution of snow on the surface. This, together with the above mentioned processes, affects the light transmission and thus affects one of the main limiting factors for algae growth.

Sea-ice physical, chemical and biological properties are highly variable in time and space, thus field sampling and producing representative model output of ice algae are extremely challenging. A big question concerning sea ice sampling is how representative of the surrounding area are the measurements taken at a certain location. Such a problem arises also when trying to upscale these observations, since upscaling always means parameterization, averaging and simplification. Thus, it is fundamental to determine the temporal and spatial scales of variability of sea-ice algae, and even more to determine any relationship of sea ice algae distribution with the variability of physical and chemical sea ice properties. In addition, special environments for algae growth and survival, such as very young ice and deformed ice have not been fully characterized so far. Particular ridges are an under-sampled component of the sea ice environment in terms of their biogeochemical properties. The presence of ridges may offer an inhomogeneous, albeit favorable, environment for sea-ice algae growth. Thus, particular attention should be given to ridged and deformed ice, which is commonly overlooked as potential algae growth site.

Sea ice harbors a distinct community of prokaryotic and eucaryotic photo- and heterotrophs (Hardge et al. 2017). Sea ice algae contribute substantially (5 to ca 60 %) of total Arctic primary production (Fernández-Méndez et al. 2015), and support not only an ice based food web, but also provide important food pulses to pelagic and benthic communities. Within the ice, newly formed particulate matter is consumed by various protozoa and metazoa, including Acoela, Crustacea and Rotifera. Sea ice algae are also a source of dissolved organic matter, which is channeled through a microbial network back into the particulate food web. All these ice inhabitants have typically sizes of less than 1 mm, to be able to explore the branched network of brine channels within the ice. In addition, ice algae can be directly consumed by under-ice amphipods and migratory zooplankton. Also specialized curtain-like algal mats have been observed under sea ice, mainly consisting of *Melosira arctica*. Vertical export of sea ice-derived organic matter is mainly driven either by organism release due to ice melt, or by fecal pellet production of grazing amphipods and zooplankton. Changes in sea ice habitat structure and ice algal production will affect the trophic transfer of sea ice-derived carbon through the under-ice community into pelagic food webs. A key role in transferring carbon from ice algae to higher trophic levels is taken by species dwelling at the ice-water interface, such as *Calanus* spp., *Apherusa glacialis* and polar cod *Boreogadus saida* (Kohlbach et al. 2016). The decline of the sea ice can alter the composition and biodiversity of the sea ice flora and fauna. Biodiversity in turn plays a vital role for the stability of ecosystem processes, and is positively coupled with the efficiency of important ecosystem functions, e.g. fluxes of energy, nutrients and organic matter. Thus understanding the relationship of the biodiversity of sea-ice biota with ecosystem functions is important for predicting consequences of climate change in an Arctic ecosystem.

Summer sea ice retreat alters water mass formation and convection, which may have profound effects on natural biogeochemical cycles between sea ice and seawater. Especially feedback effects to pathways of climatically relevant trace gases will loom large in the equation of change. Increasing water stratification during sea ice melting is likely to limit nutrient availability in near-surface water, which in turn hampers the enhancement of primary production. A characteristic feature of the Arctic Ocean is distinct post-bloom nutrient limitation. Nutrient limitation may be also a possible regulator of methane ($CH_4$) production in surface water. Methanogens form $CH_4$ via various pathways commonly classified with respect to the type of carbon precursor utilized, e.g. the methylothrophic pathway indicates the intact conversion of a methyl group to $CH_4$. The contribution of methylated substrates is potentially large in sea ice, and methylothrophic methanogenis may be a principal pathway from which $CH_4$ is readily formed by microbial activity. However, the direct evidence of this role of methylated substrates in sea ice is still lacking. In this context, the degradation of dimethylsulfoniopropionate (DMSP), an abundant methylated substrate in surface water and sea ice becomes pivotal. DMSP is produced by marine phytoplankton and sea ice algae. Cleavage of DMSP can be carried out by bacteria or by phytoplankton, and leads to formation of DMS (dimethylsulfide) or methanethiol. DMS, an important climate-cooling gas, partly escapes to the atmosphere where it is oxidized to sulphuric acid and methanesulfonic acid. Methanethiol is a key reactive intermediate utilized as sulphur and carbon sources for biosynthesis or energy generation. In anaerobic environments methanethiol act also as precursor for $CH_4$ production. In the ocean, processes producing $N_2O$ are mainly being controlled by organic matter and dissolved oxygen. This trace gas is mainly produced by nitrification or nitrifier denitrification under oxic and also microaerophilic conditions. Conversely, partial denitrification can produce $N_2O$ under suboxic conditions, whereas the complete reduction is the only reaction able to consume $N_2O$ under suboxic/anoxic conditions. The assimilative reduction of $N_2O$ to $NH_4^+$ ($N_2O$ fixation) may be responsible for a certain amount of consumption, but not much is known so far.

The sea ice ecology group of PS106 aims for the following objectives:

- Studying the importance of spatial scales for estimating physico-chemical sea ice properties, ice algae biomass and primary production;
- Investigating the role of light for the production and biodiversity of sea ice algae;
- Studying the importance of physical and biogeochemical properties of sea ice ridges for the growth conditions of ice algae;
- Analyzing the abundance, biodiversity and community structure of sea ice-associated biota and quantifying ecosystem functions and their relationships with biodiversity;
- Using molecular and isotopic biomarkers to trace sea ice-derived carbon in pelagic food webs;
- Quantifying the vertical export under sea ice;
- Identifying the main triggering processes for climate-relevant compounds (CH4, N2O and DMS) in sea-ice and in the underlying water column and quantifying the fluxes across the water-sea ice-air interfaces following the melting cycles in the Arctic Ocean.

## Work at sea

*General sea ice work*

Sea ice cores will be taken for biological, chemical and biogeochemical analyses every other or every third day during the ice camp of PS106.1 and at individual ice stations during PS106.2. We will further sample sack holes, the water under the ice and if present, melt pond water. The depth of the sampling under the ice will be based on vertical profiles of a CTD and fluorescence probe which will be obtained prior to the water sampling. We will measure environmental parameters, such as sea ice temperature, snow depth, free board and ice thickness. Hyperspectral radiometers will be used to measure the spectral composition of the light under the ice for estimating ice-algae biomass. Spectral measurements will be conducted with sensors mounted on Three different platforms: an L-arm for point measurements and calibration (PS106.1 & 106.2), the Surface and Under-Ice Trawl (PS 106.2), and the ROV of the sea ice physics group (PS 106.1 & 106.2). At L-arm survey sites, ice cores will be extracted and processed for chlorophyll a content in order to validate the relationship of ice algal biomass with the under-ice spectral light properties (Lange et al., 2016).

We aim to collect the following core parameters: salinity, nutrients, coloured dissolved organic matter (CDOM), dissolved inorganic carbon (DIC), and filters for particulate N, P and C. Additionally, algae biomass and taxonomic composition will be determined by size-fractionated chlorophyll, marker pigments, Illumina sequencing and cell counts (microscopy and flow cytometer). Also biogenic silicate, particulate organic carbon and nitrogen (POC, PON) and the isotopic composition of POC and PON (δ13CPOC and δ15NPON) will be determined. Flow cytometer and marker pigments will be sampled from the CTD casts in collaboration with the water column biogeochemistry group. Flow cytometer measurements of the pico- and nanoplankton and fractionated chlorophyll from all habitats will be directly counted or measured, respectively. All other samples will be stored and measured at the AWI, UiT, and WMR.

Primary production measurements of sea ice algae and phytoplankton will be conducted in *in-situ* incubations of ice core segments and water samples with stable isotope tracers ($^{13}C$, $^{15}N$). After incubations, samples will be melted, filtered and stored for later analyses in a stable isotope lab. In parallel to these measurements, the export of organic matter from the ice will be determined using short-term sediment trap samples in 5 and 20 m water depth. Material from the traps will be used to determine the quantity and quality of the exported material (pigments, stable isotopes, eDNA). These data will be augmented by deployment of gel traps to further determine the size and form spectrums of sinking matter.

To assess the relationship between sea ice habitat properties, food web structure and biodiversity, we will sample the meio- and microfauna and microbial communities in sea ice as well as the microzooplankton composition of the ice-water interface layer. Based on melted sea ice, bacteria, heterotrophic protists and meiofauna will be quantified either in fixed samples (fluorescence microscopy) or alive (meiofauna). Meiofauna will be sorted alive and fixed for later taxonomic and food web analyses (e.g. DNA sequencing, stable isotope analysis).

Insights into food web interactions will be achieved through food web markers and grazing experiments. The trophic significance of ice algae in Arctic pelagic food webs will be investigated with isotopic biomarkers. To sample the trophic baseline needed for the interpretation of biomarker results (ice algae and phytoplankton), melted sea ice cores and seawater samples will be filtered. Ice algae-derived carbon will be traced from the ice-associated community through the pelagic system into the benthos by collecting abundant taxa from all three environments (see chapters 14, 15). A stable isotope turnover experiment will be conducted with one or two meiofauna taxa to address the time it takes for changing food sources to be assimilated by these organisms.

A time series will be performed to determine the climate-relevant compounds variability along the late spring season. We intend to measure dissolved gases (CH4 and N2O), DMS, DMSP and δ13C-CH4 concentrations in sea ice and surface sea water. Water samples will be collected from Niskin bottles mounted on a rosette sampler at discrete depths throughout the water column down to 200 m. The number of sampling depths depends of the fluorescence and tO2- sensor signals. We will sample one-year and multi-year sea ice and brine by taking cores with a standard corer. Sea ice cores will be sectioned and melted at 4°C. Methane concentration will be measured on board by gas chromatography (GC) equipped with a flame ionization detector (FID). Gas samples will be stored for analyses of the d13C values of methane by mass spectrometry in the home laboratory. DMS and DMSP concentrations will be measured on board by GC equipped with a pulsed flame photometer (PFPD) and by GC equipped by a flame photometer (FPD), respectively. N2O will be measured either on board or in the home laboratory by GC.

If possible, sampling will further be carried out on surrounding ice floes by using zodiac and helicopter.

*Experiments*

*A. The role of scales for biological sea ice sampling*

At the beginning and toward the end of PS106.1 we want to study the spatial scales of ice algae biomass. We will set up a nested approach (Miller et al., 2015) to extrapolate detailed information to larger scales, based on distinguishing hierarchical layers of detail. In particular, a primary scale corresponding to the ice floe (~100m) will define the study area in all its variation. The secondary scale will serve to determine the representativeness of each site. This scale comprises a finite number of selected sites, separated by a distance of ~ 10m and covering all the possible sea-ice conditions (except for ridges, treated separately). Each of these sites is further divided into a 1 m grid, the tertiary scale. Each point of the grid represents one individual measurement. When possible, further sampling will be carried out by zodiac or helicopter to assess sea ice variability on a larger scale (~500-1,000 m). Bottom sections for fractionated chlorophyll, POC and flow cytometer will be collected for all samples while Meiofauna and DNA will be collected frequently.

*B. Gardening*

On three fields of 5x5 m the snow coverage will be manipulated and in collaboration with the sea ice physic team the light conditions under the ice will be monitored every other day and subsamples for flow cytometer, microscopy, DNA and fractionated chlorophyll will be taken. Ideally, twice a day the spectral composition measurement surveys will be performed by ROV to estimate the temporal evolution of ice algae and to investigate the influence of snow on light availability and algae growth. Measurements of sea ice algal and phytoplankton primary productivity will be conducted at each experimental site at three time points. These measurements will be corroborated by regular PHYTO-PAM P/I curve measurements.

*C. Ridge study*

The aim is to sample at least one large ridge for physical and biogeochemical characterization during PS 106.1. In particular, snow transects crossing the ridge will be conducted to characterize the snow distribution in a deformed environment. Ice thickness probes will be used and light transmitted through the ridge structures will be measured with remotely operated vehicles (ROV; in cooperation with the sea-ice physics group at AWI). Ice cores will be extracted from the ridge(s) to analyze the vertical structure (porosity, presence of entrapped sea water). Samples for nutrients, biodiversity, microscopy, flow cytometer and fractionated chl-*a* will be taken from the ice and the water. Primary productivity measurements will assess the activity of the encountered ice algal communities.

*D. Trace gases*

We plan to deploy a chamber system connected to an auto analyzer Los Gatos Research for continuous measurements of greenhouse gases fluxes across the sea-ice air interface. The measurements will depend on the logistic plan and sea ice conditions. To gain a better understanding on the possible control/influences of microbial community on $CH_4$ flux to the atmosphere we will additionally conduct incubation experiments to measure $CH_4$ oxidation rates in melted sea ice and/or sea water collected with Niskin bottles. Experiments for assimilative $N_2O$ fixation will performed using a stable isotope technique in melted sea ice and sea water. $^{15}N$-labeled $N_2O$ gas will be the substrate during the experiments to measure $N_2O$ fixation rates by incubating samples.

**Preliminary (expected) results**

The aim of this study is to understand the variability and biodiversity of the sea ice-associated biomass with respect to the sea ice conditions and nutrient availability, to assess the role of sea-ice biota for the cryo-pelagic, cryo-benthic coupling under different environmental scenarios from the shelf to the deep sea basin and its temporal development from spring to summer. Linking the various components of the food webs to a joint ice-related ecopath model will improve assessments of the role of climate change on the carbon cycle of the Arctic Ocean.

The chl-*a* data collected will be used to assess the sub-kilometer scales of variability in biological and physical parameters. The development of functions able to represent such variability will improve the parameterization for sea-ice algae modeling that are now used in large-scale global circulation models (e.g., MITgcm, FESOM). The consequences of under-sampling will be assessed with the aim to develop a sampling strategy and protocol that can be used for future field work (e.g., MOSAiC). Investigating the temporal evolution of the biological system will help to identify the timing and length of the spring bloom period, a key process to be represented in numerical simulations. Moreover, a set of conditions and parameters obtained from these field measurements will be used to feed numerical simulations.

In addition, our goal is to achieve high data resolution by continuous measurements of greenhouse gases fluxes across water-sea ice-air interfaces along the late spring; this will also help us to test the sea ice permeability differences through time. We will be able to know the budget of relevant- climate compounds in both compartments, sea ice and sea water, influenced by a melting cycle and to distinguish how the physical and biogeochemical processes trigger concentration/saturation of trace gases.

### Data management

Almost all sample processing, such as chemical measurements, species identifications and quantifications, will be carried out in the home laboratories at AWI, WMR and UiT. As soon as the data are available they will be accessible to other cruise participants and research partners on request. Depending on the finalization of PhD theses and publications, data will be submitted to PANGAEA within 1-2 years. The unrestricted availability from PANGAEA will depend from the progress of related PhD theses based on the data.

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## 13. INVESTIGATIONS ON THE COMPOSITION OF THE BENTHIC FAUNA DERIVED FROM AN ICE-FLOE DRIFT STATION OFF SVALBARD

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### Objectives

There are still large knowledge gaps on the life cycles and several aspects of *B. saida* biology, especially with respect to time spend in deeper water layers. However, feeding and shelter from predators in the benthic realm might be of considerable importance with regard to survival of adult *B. saida* and thus for reproductive success of the species. To estimate the susceptibility of the benthic ecosystem to future changes induced by Climate Change and their potential impact on Polar cod distribution, it is important to gain more information on the composition of the benthic community in terms of abundance and diversity, and its dependency on sea ice algae.

**Work at sea**

Samples will either be taken by means of an RP-sledge or a giant box corer during PS 106.1. The RP-sledge, a type of an epibenthic sledge with the same position and opening height over the seafloor as more modern epibenthic sledges (Brandt et al., 2013; Brenke 2005), will be deployed in case the ice floe has a drift which allows trawling while the RV *Polarstern* is staying in contact to the ice floe. The giant box corer will be used in case that there is no or only neglectable drift of the ice floe. The use of the RP-sledge will have priority over the giant box corer, as it usually yields a higher number of invertebrate species and individuals.

On board, the samples will be immediately fixed in 96 % precooled ethanol in order to allow also future molecular studies or in formaline (part of the material from the giant box-corer samples). Large and well preserved animals will be photographed alive to document the colour patterns (in case a camera is on board from the planktologists and can be used). Abundant benthic macro- and megafauna will be preserved at -80°C for subsequent biomarker analysis (see chapter 12, 14).

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# 14. UNDER-ICE FAUNA, ZOOPLANKTON AND ENDOTHERMS

H. Flores (AWI, UHH), J. Ehrlich (AWI, UHH), B.A. Lange (AWI), D. Kohlbach (AWI, not on board), M. Graeve (AWI, not on board), A. Orlov (VNIRO), Erik Sulanke (UHH), B. Niehoff (AWI), Nicole Hildebrandt (AWI), Martin Doble (PolarScientific), F.L. Schaafsma (WMR), A. Meijboom (WMR), B. Fey (NIOZ), S. Kühn (WMR), E. Bravo Rebolledo (WMR), M. van Dorssen (van Dorssen Metaalbewerking), J.A. van Franeker (WMR, not on board), Bram Couperus (WMR, not on board), Dirk Burggraaf (WMR, not on board), R. Gradinger (UiT), B. Bluhm (UiT, not on board), B. Hassett (UiT), E. Kunisch (UiT)

## Objectives

The Arctic Ocean is facing drastic changes, most evidently a significant decline of the extent and duration of sea ice coverage. This process is accompanied by ocean warming in some areas of the Arctic Ocean, and increasing acidification. A reduction and change of sea ice habitats will have consequences on ecosystem functioning since, at high latitudes, ecosystems thrive on carbon produced by ice-associated algae. Grazers in the ice-water interface layer, such as under-ice amphipods and copepods, as well as young polar cod *Boreogadus saida* feeding on them, play a key role in transferring sea ice-derived carbon into pelagic food webs, and ultimately to the birds and mammals inhabiting the Arctic (Kohlbach et al. 2016, in press). Reduction of sea ice habitats may result in insufficient resources for juvenile polar cod and in a potential loss of connectivity between central Arctic sea ice habitats and shelf-based populations (David et al. 2016). Further decline and structural change of Arctic sea ice may thus lead to habitat loss and reduced food availability for this fish. A major decline of polar cod stocks can cause severe ramifications in Arctic ecosystems, and can particularly affect populations of higher predators, such as seals and polar bears *Ursus maritimus*. Our group aims to better understand potential impacts of changing sea ice habitats for polar cod, its prey, and its predators.

During PS106.2, we will sample the physical and biogeochemical habitat properties and biodiversity of the sea-ice associated habitat, with an emphasis on polar cod and its ice-associated and pelagic prey species. The abundance and distribution of under-ice fauna is poorly understood due to the inaccessibility of the under-ice habitat. New sampling methods are therefore warranted to observe and quantify this important functional group of the food web, and its resilience to changing sea ice habitats. To investigate the vertical and horizontal distribution and abundances of abundant zooplankton and under-ice fauna species, meso- and macrofauna will be sampled with a Surface and Under-Ice Trawl (SUIT), a Rectangular Midwater Trawl (RMT), a Multinet, an ROV-mounted under-ice net, echosounders (*Polarstern's* EK60/80 and Acoustic Zooplankton and Fish Profilers, AZFPs), and an acoustic imaging camera. With the zooplankton recorder LOKI (light frame on-sight key species investigator, Fig. 14.1), we will continuously take pictures from the organisms floating in the water column from 1,000 m depth to the surface and during horizontal ROV-transects, which allows to exactly identify horizontal and vertical distribution patterns in relation to environmental conditions.

Polar cod constitutes the staple food of various Arctic and North-Atlantic bird and seal species, thereby indirectly ensuring food sources of polar bears. To assess the relevance of sea ice-associated resources and polar cod for higher trophic levels, endotherm surveys will be conducted to map the association of seabirds, polar bears, seals and whales with the distribution of polar cod and sea-ice habitat properties.

**Work at sea**

*Under-ice sampling*

The association of polar cod and other under-ice fauna with sea ice properties and various environmental parameters will be investigated with a Surface and Under-Ice Trawl (SUIT: van Franeker et al. 2009). The SUIT has two nets, a 0.15 mm mesh plankton net, and a 7 mm mesh shrimp net. During SUIT trawls, data from the physical environment are recorded, e.g. water temperature, salinity, fluorescence, ice thickness, and hyper-spectral light transmission. SUIT deployments will be conducted at regular intervals along the SiPCA transects.

During PS 106.1 and during sea ice stations of PS 106.2 we will study the horizontal and vertical distribution of meso- and macrofauna using various innovative and experimental approaches:

- An Acoustic Fish and Zooplankton Profiler (AZFP) will be deployed close to the biological sampling sites to determine the vertical distribution of zooplankton and fish under the sea ice with high temporal resolution;
- The ROV of the sea ice physics group will be used to sample under-ice macrofauna with a zooplankton net scraping the underside of sea ice;
- A LOKI will be mounted on the ROV to sample the horizontal distribution of mesozooplankton in the ice-water interface layer;
- An acoustic imaging camera will be deployed under the ice to observe and monitor the habitat use of polar cod Boreogadus saida.

*Pelagic sampling*

Particulate Organic Matter (POM) will be collected from filtered seawater obtained from the CTD rosette. Chlorophyll samples will be filtered from CTD rosette water samples to calibrate fluorometers built in the ship's CTD and the SUIT.

Mesozooplankton composition and depth distribution will be determined by means of vertical Multi net tows from 1,000 m depth to the surface. In addition, optical surveys with the LOKI will be conducted to determine the small-scale distribution of zooplankton in the water column. We will also mount an acoustic backscatter system (Aquascat, equipped with 0.3, 0.5, 1, 2 and 4 MHz transducers) on the LOKI. This will allow for parallel sampling of optical and acoustical data. Bongo net hauls will be taken to collect organisms for biochemical analyses and trophic biomarkers (stable isotopes, carbon, nitrogen, protein and lipid content, fatty acid composition).

A Rectangular Midwater Trawl (RMT) will be used to sample deeper-dwelling key species of the pelagic food web, such as euphausiids, amphipods, and fishes down to 200 m water depth. The RMT consists of a 1 $m^2$ opening 0.3 mm mesh mesozooplankton net mounted on top of a 5 mm mesh macrozooplankton net. In addition, *Polarstern's* EK60/80 echosounder will be running during steaming to map the distribution of fish and macrozooplankton in the water column continuously.

Organisms caught with nets will be sampled and stored in formalin, -80°C and -20°C, and will be studied further using microscopy, DNA analysis, calorific content analysis and C/N ratio analysis.

*Biomarker analysis*

The trophic significance of ice algae in Arctic pelagic food webs will be investigated with molecular and isotopic biomarkers (see chapter 12, 13). To this end, organisms caught with SUIT, RMT and other gear will be sampled and stored at -80°C, and later submitted to compound-specific stable isotope analysis (CSIA) at the AWI. To sample the trophic baseline needed for the interpretation of CSIA results (ice algae and phytoplankton), melted sea ice cores and seawater samples will be filtered.

*Diet analysis*

To further investigate the significance of ice algae in the diet of under-ice fauna, and the significance of under ice fauna in the diet of polar cod and top predators, stomach contents and energy content of trophic key species will be investigated. To further link the sea ice food web components, we will conduct DNA analysis of the stomach contents of under-ice fauna including *Boreogadus saida*, and compare those to traditional stomach content analysis and trophic markers.

*Top predator censuses*

Quantitative censuses of top predator community (seabirds and marine mammals) will be conducted in the study area and on transects to and from the study area. This will be a combination of ship-based and helicopter-based surveys. Ship based censuses are conducted from the moving ship from two special outdoor observation posts that are attached to the front guard-rail of the Peildeck of *Polarstern*. Bird densities are assessed by band transect surveys with snapshot methodology for individuals in flight (Tasker et al. 1984). For marine mammals, viz. seals, polar bears and whales, line-transect methodology is added (Buckland et al. 2001). Allometric formulas based on body mass are used to translate density data for individual species to energy and food requirements per surface area (van Franeker et al. 2002).

**Preliminary (expected) results**

Post-expedition analysis of biological samples will comprise diet analysis, trophic biomarker analysis, otolith studies, and genomics. The resulting datasets will enable us to

1. identify sea ice habitats favourable for polar cod in terms of physical properties, prey availability and biodiversity;
2. quantify the carbon flux between sea ice, pelagic communities, polar cod and top predators;
3. study the connectivity between central Arctic under-ice populations of polar cod and shelf-based spawning stocks;
4. identify critical habitats for the viability of polar cod stocks and marine endotherms, and assess their vulnerability to climate change.

Furthermore, we expect to obtain a comprehensive dataset of the distribution and diversity of pelagic and under-ice fauna of the Arctic Ocean and their relationship with the sea-ice habitat.

**Data management**

Almost all sample processing, such as chemical measurements and species identifications and quantifications, will be carried out in the home laboratories at AWI and Wageningen Marine Research. As soon as the data are available they will be accessible to other cruise participants and research partners on request. Depending on the finalization of PhD theses and publications, data will be submitted to PANGAEA, and will be open for external use.

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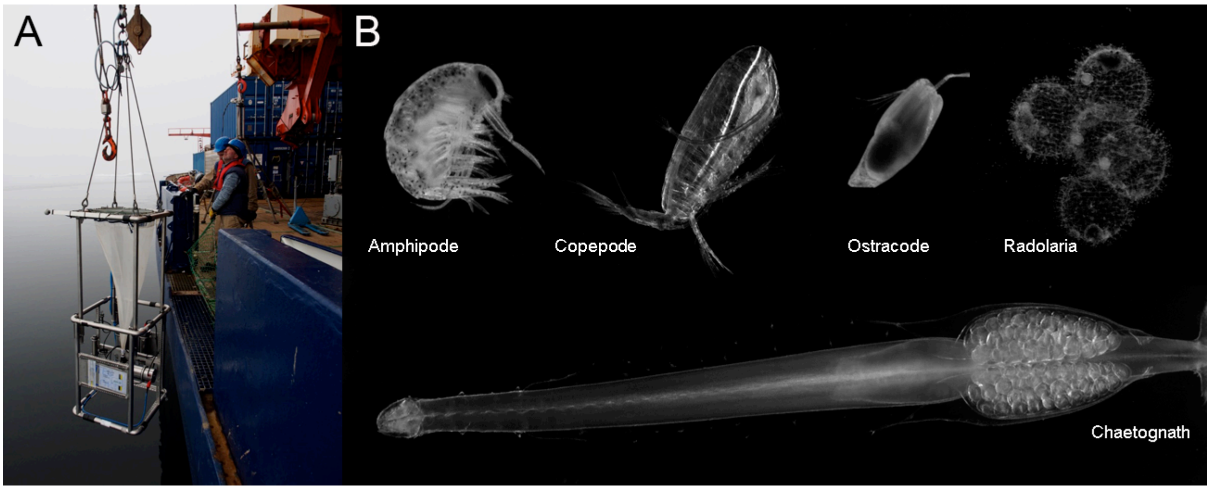


*Fig. 14.1: the LOKI system during deployment (A, ©Martin Doble, PolarScientic) and a compilation of photographs taken by LOKI (B, ©N. Hildebrandt, AWI).*

# 15. CLIMATE SENSITIVITY IN ARCTIC FISH: PHYSIOLOGICAL DIFFERENTIATION AND GENETIC BASIS OF DISTINCT POPULATIONS OF THE POLAR COD *BOREOGADUS SAIDA*

C. Bock, N. Koschnick, K. Mintenbeck, F. Mark (not on board), G. Lannig-Bock (not on board), M. Lucassen (not on board) (all AWI)

## Objectives

Due to increasing $CO_2$ in the atmosphere at a fast rate marine organisms already face growing ocean warming and acidification. In particular, the response of complex organisms will likely affect every aspect of their biochemistry and physiology possibly culminating in shifting geographical distribution on a larger scale. The responses to fluctuating environmental factors are ultimately set by the genetic interior of an organism. However, thermal windows of individual macromolecules are usually much wider than the temperature window of the entire organism, and the integration of molecules into functional units and networks up to the whole organism level must be taken into account for an understanding of climate-driven evolution.

The Arctic Ocean is particularly affected by on-going climate change. To date, northward-directed shifts in species distribution have been shown for some boreal fish including the Atlantic cod (*Gadus morhua*). This might affect native polar species like the Polar cod, *Boreogadus saida* due to increasing predation pressure and food competition, as these species cannot escape further to the North. Moreover, increasing temperatures, ocean acidification and retreating sea ice may have adverse effects on physiological performance and fitness of polar fish. During the joint project "BIOACID II", we started already an integrated approach on species response/vulnerability and possible interaction of the confamilial *B. saida* and *G. morhua* (Kunz et al. 2016), and reasonable molecular genetic data have been acquired (Lucassen et al. unpublished). This comparative approach turned out to be an ideal model for studying the specific differences of cold adaptation in the Arctic and Antarctic fish fauna.

*B. saida* populates different habitats during its life cycle from benthos to open water and the underside of sea ice. These opposing habitats with their divergent food supply will possibly affect the physiology of this species. Within the small spatio-temporal scales of SiPCA we will conduct comprehensive comparative physiological and molecular genetic studies of the different populations from all available habitat types. We aim to (i) estimate acclimatory capacities/sensitivity towards combined treatments of warming and hypercapnia, (ii) determine the level of cold adaptation, and (iii) compare these laboratory treated samples to *in-situ* samples from the field. The analyses comprise global (RNA-Seq) and targeted (qPCR) gene expression techniques on the background of the population genetic structure, assessment of cellular energy budgets and allocation, as well as metabolic profiling (by means of untargeted nuclear magnetic resonance spectroscopy, NMR).

Alive fish in the most pristine condition possible is needed for our physiological experiments, which are mostly done at the home institute. Therefore, we also employ new catching gears like a fish-lift that allows for catching fishes alive and without harm.

**Work at sea**

By means of bottom and pelagic trawls we aim to survey the fish fauna along the cruise line in close collaboration with the other groups (H. Flores et al., Chapter 14). The bottom trawl used will be a commercially–sized 140' bottom trawl; the aforementioned fish-lift will be mounted on top of the bottom trawl. Starting on the upper shelf we will conduct surveys down the continental slope down to about 1,200 m. In ice-covered areas trawling with the SUIT (Chapter 14) will complement the fishing effort. If possible, pelagic trawls will be employed at selected stations to assess fish communities in the open water.

All catches will be analysed for species composition, individual size and biomass, sex and maturity stage. Fin-clips from all specimens will be taken and preserved in ethanol for population genetics. Additional tissue samples will be taken directly after the catch and flash-frozen in liquid nitrogen for later molecular and physiological analyses at the home institute. Alive *B. saida* in good condition will be directly transferred to the aquarium systems and kept alive until transport to the home institute. All the work and analyses will be done in close collaboration with the other groups on board. If available, all other fish species, namely the Arctic cod *Arctogadus glacialis* and possibly *G. morhua*, will be sampled in the same way.

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# 16. TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

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| DWD | Deutscher Wetterdienst<br>Geschäftsbereich Wettervorhersage<br>Seeschifffahrtsberatung<br>Bernhard Nocht Str. 76<br>20359 Hamburg<br>Germany |
| DZMB | German Centre for Marine Biodiversity Research (DZMB)<br>c/o CeNak, Zoological Museum<br>Martin-Luther-King-Platz 3<br>20146 Hamburg<br>Germany |
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| 03. | Westphal, Henning | Ch.Eng. |
| 04. | Spielke, Steffen | 1.Offc.Lad. |
| 05. | Kentges, Felix | 2.Offc. |
| 06. | Peine, Lutz | 2.Offc. |
| 07. | Rudde-Teufel | Doctor |
| 08. | Hofmann, Jörg | Comm.Offc. |
| 09. | Schnürch, Helmut | 2.Eng. |
| 10. | Buch, Erik-Torsten | 2.Eng. |
| 11. | Rusch, Torben | 2.Eng. |
| 12. | Brehme, Andreas | Elec.Tech. |
| 13. | Ganter, Armin | Electron. |
| 14. | Markert, Winfried | Electron. |
| 15. | Winter, Andreas | Electron. |
| 16. | Feiertag, Thomas | Electron. |
| 17. | Schröter, Rene | Boatsw. |
| 18. | Neisner,Winfried | Carpenter |
| 19. | Clasen, Nils | A.B. |
| 20. | Schröder, Norbert | A.B. |
| 21. | Burzan, Gerd-Ekkehard | A.B. |
| 22. | Hartwig-Labahn, Andreas | A.B. |
| 23. | Fölster, Michael | A.B. |
| 24. | Müller, Steffen | A.B. |
| 25. | Brickmann, Peter | A.B. |
| 26. | Sedlak, Andreas | A.B. |
| 27. | Schröder, Christoph | A.B. |
| 28. | Beth, Detlef | Storekeep. |
| 29. | Plehn, Markus | Mot-man |
| 30. | Klein, Gert | Mot-man |
| 31. | Krösche, Eckard | Mot-man |
| 32. | Dinse, Horst | Mot-man |
| 33. | Watzel, Bernhard | Mot-man |
| 34. | Meißner, Jörg | Cook |
| 35. | Tupy,Mario | Cooksmate |
| 36. | Möller, Wolfgang | Cooksmate |
| 37. | Wartenberg, Irina | 1.Stwdess |
| 38. | Schwitzky-Schwarz Carmen | Stwdss/KS |
| 39. | Hischke, Peggy | 2.Stwdess |
| 40. | Grigull, Elke | 2.Stwdess |
| 41. | Krause, Tomasz | 2.Steward |
| 42. | NN | 2.Steward |
| 43. | Chen, Quan Lun | 2.Steward |
| 44. | Ruan, Hui Guang | Laundrym. |

**PS106/2**

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| 02. | Lauber, Felix | 1.Offc. |
| 03. | Westphal, Henning | Ch.Eng. |
| 04. | Spielke, Steffen | 1.Offc.Lad. |
| 05. | Kentges, Felix | 2.Offc. |
| 06. | Peine, Lutz | 2.Offc. |
| 07. | Rudde-Teufel | Doctor |
| 08. | Christian, Boris | Comm.Offc. |
| 09. | Schnürch, Helmut | 2.Eng. |
| 10. | Buch, Erik-Torsten | 2.Eng. |
| 11. | Rusch, Torben | 2.Eng. |
| 12. | Brehme, Andreas | Elec.Tech. |
| 13. | Frank, Gerhard | Electron. |
| 14. | Markert, Winfried | Electron. |
| 15. | Winter, Andreas | Electron. |
| 16. | Feiertag, Thomas | Electron. |
| 17. | Schröter, Rene | Boatsw. |
| 18. | Neisner,Winfried | Carpenter |
| 19. | Clasen, Nils | A.B. |
| 20. | Schröder, Norbert | A.B. |
| 21. | Burzan, Gerd-Ekkehard | A.B. |
| 22. | Hartwig-Labahn, Andreas | A.B. |
| 23. | Fölster, Michael | A.B. |
| 24. | Müller, Steffen | A.B. |
| 25. | Brickmann, Peter | A.B. |
| 26. | Sedlak, Andreas | A.B. |
| 27. | Schröder, Christoph | A.B. |
| 28. | Beth, Detlef | Storekeep. |
| 29. | Plehn, Markus | Mot-man |
| 30. | Klein, Gert | Mot-man |
| 31. | Krösche, Eckard | Mot-man |
| 32. | Dinse, Horst | Mot-man |
| 33. | Watzel, Bernhard | Mot-man |
| 34. | Meißner, Jörg | Cook |
| 35. | Tupy,Mario | Cooksmate |
| 36. | Möller, Wolfgang | Cooksmate |
| 37. | Wartenberg, Irina | 1.Stwdess |
| 38. | Schwitzky-Schwarz, Carmen | Stwdss/KS |
| 39. | Hischke, Peggy | 2.Stwdess |
| 40. | Grigull, Elke | 2.Stwdess |
| 41. | Krause, Tomasz | 2.Steward |
| 42. | NN | 2.Steward |
| 43. | Chen, Quan Lun | 2.Steward |
| 44. | Ruan, Hui Guang | Laundrym. |