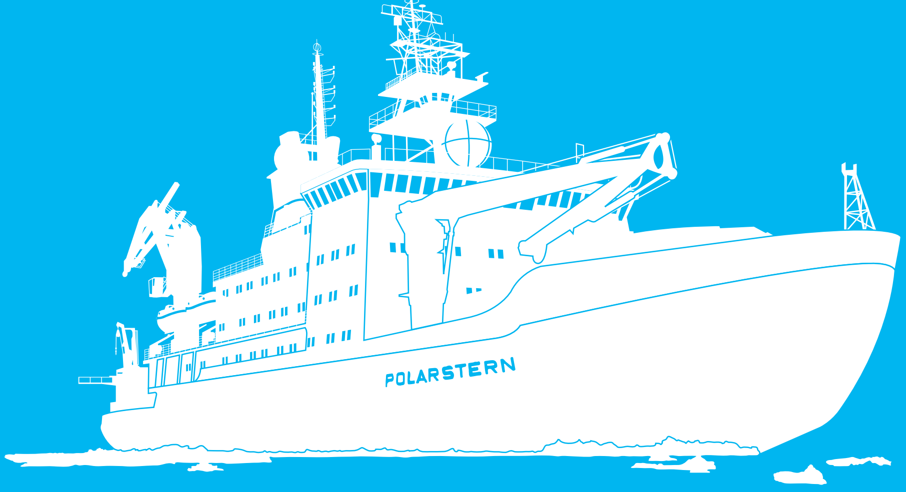
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

EXPEDITION PROGRAMME PS122

Polarstern

PS122
Tromsø - Bremerhaven
20 September 2019 - 14 October 2020

Coordinators:	Rainer Knust, Markus Rex
Chief Scientists:	Markus Rex, Christian Haas, Torsten Kanzow, Markus Rex, Dieter Wolf-Gladrow, Markus Rex



HELMHOLTZ

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Alfred-Wegener-Institut
Helmholtz-Zentrum
für Polar- und Meeresforschung
Am Handelshafen 12
D-27570 Bremerhaven

Telefon:	+49 471 4831-0
Telefax:	+49 471 4831-1149
E-Mail:	info@awi.de

Website:	http://www.awi.de
Email Coordinators:	rainer.knust@awi.de, markus.rex@awi.de
Email Chief Scientists:	markus.rex@awi.de, christian.haas@awi.de, torsten.kanzow@awi.de, dieter.wolf-gladrow@awi.de

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The Programme provides information about the planned goals and scientific work programmes of expeditions of the German research vessel *Polarstern*.
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Editorial editing and layout
Birgit Reimann

Alfred-Wegener-Institut
Helmholtz-Zentrum für Polar- und Meeresforschung
Am Handelshafen 12
27570 Bremerhaven
Germany

www.awi.de
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PS122

MOSAiC

20 September 2019 - 14 October 2020

Tromsø - Bremerhaven

MOSAiC
International
Arctic Drift
Expedition

Chief scientists

Markus Rex	**PS122/1: 20 Sep 2019 – 15 Dec 2019**
Christian Haas	**PS122/2: 15 Dec 2019 – 15 Feb 2020**
Torsten Kanzow	**PS122/3: 15 Feb 2020 – 15 Apr 2020**
Markus Rex	**PS122/4: 15 Apr 2020 – 15 Jun 2020**
Dieter Wolf-Gladrow	**PS122/5: 15 Jun 2020 – 15 Aug 2020**
Markus Rex	**PS122/6: 15 Aug 2020 – 14 Oct 2020**

Coordinators

Rainer Knust, Markus Rex

Contents

1. ÜBERBLICK UND FAHRTVERLAUF

M. Rex (DE.AWI)

Die Expedition PS122, alias MOSAiC (Multidisciplinary Drifting Observatory of the Study of Arctic Climate) und wird am 20. September 2019 von Tromsø (Norwegen) in See stechen. PS122 ist eine ganzjährige Expedition im zentralen Arktischen Ozean und unterteilt in sechs Fahrtabschnitte (PS122/1 – PS122/6). PS122 wird am 14. Oktober 2020 in Bremerhaven enden.

Der Beginn von PS122 wird von dem russischen Forschungseisbrecher *Akademik Fedorov* vom Arctic and Antarctic Reserach Institute (AARI) begleitet werden. *Akademik Fedorov* wird am 20. September 2019 kurz nach *Polarstern* in Tromsø ablegen. Beide Schiffe werden gemeinsam zur Eiskante und durch das Eis fahren und werden eine adäquate Eisscholle suchen. Auf der Anfahrt wird ein Zwischenstopp gemacht, um vier Verankerungen im Bereich 82°N und 119°O (siehe blau-schwarzer Punkt in Abb. 1.1) aufzunehmen. Nach circa acht Tagen ist geplant, am potentiellen Startpunkt (85°N und 135°O) anzugelangen und dort dann mit der Suche nach einer passenden Eisscholle zu beginnen. Für die Suche stehen Satellitendaten, Meereisvorhersagen und wissenschaftliche Experten auf der *Polarstern* und der *Akademik Fedorov* zur Verfügung. Die Suche soll nach fünf Tagen abgeschlossen sein und somit ist geplant, dass ab dem 04. Oktober an der gefundenen Eisscholle angelegt wird. Diese Scholle wird MOSAiC idealerweise für ein Jahr als zentrales Observatorium zur Verfügung stehen. Im Laufe des Winters werden die zunächst noch offenen Wasserflächen um *Polarstern* zufrieren und das Schiff wird mit der Bewegung des Meereises nahe am Pol vorbei in Richtung Fram-Straße driften. Aus Abbildung 1.2 können die Meereisdriftrouten für den Startpunkt 85°N und 135°O zum Startzeitpunkt des 15. Oktober der Jahre 2005 – 2017 entnommen werden.

Sobald die Scholle gefunden wurde, wird mit dem Aufbau der Instrumente begonnen. Die Scholle und *Polarstern* bilden das zentrale Observatorium von MOSAiC (weitere Informationen zum zentralen Observatorium können Kapitel 2.1 (Ice Camp) und 2.2 (*Polarstern*) entnommen werden). Ab dem 14. Oktober soll dann mit den Standard-Beobachtungen begonnen werden.

Während das zentrale Observatorium neben *Polarstern* aufgebaut wird, ist die *Akademik Fedorov* unterwegs, um das dezentrale Messnetzwerk auf benachbarten Schollen in bis zu 50 km Entfernung aufzubauen (weitere Informationen zum dezentralen Messnetzwerk im Kapitel 2.3). Nach Beendigung der Aufbauarbeiten des dezentralen Netzwerkes kommt die *Akademik Fedorov* für das Auftanken und den Austausch von Wissenschaftlern am 15. und 16. Oktober zurück zur *Polarstern* und bricht am 17. Oktober auf, um am 31. Oktober Tromsø zu erreichen.

Zu den sechs Fahrtabschnitten finden Versorgung mit Treibstoff und Lebensmittel und Austausch von Wissenschaftlern und Crew statt. Diese werden mittels Eisbrecher von Partnerinstituten durchgeführt. Die Versorgungen zwischen PS122/1 und PS122/2 (Mitte Dezember 2019) und PS122/2 und PS122/3 (Mitte Februar 2020) erfolgen mit der *Admiral Makarov*, einem kommerziellen russischen Eisbrecher von Rosmorport. Aufgrund des zu dicken Eises ist es im Frühjahr nicht möglich, mit Eisbrechern zur *Polarstern* zu gelangen. Daher werden die Wissenschaftler und Crew zwischen den PS122/3 und PS122/4 mit Flugzeugen ausgetauscht und es findet keine Versorgung statt. Für die Versorgung und den Personalaustausch zwischen PS122/4 und PS122/5 (Mitte Juni 2020) und zwischen PS122/5 und PS122/6 (Mitte August 2020) stehen uns die Forschungseisbrecher *Oden* (Schweden) und *Xuelong II* (China) zur Verfügung.

Um die Messungen im zentralen Observatorium und im Distributed Network zu komplettieren, wird es im Frühjahr und Sommer 2020 Flugzeugkampagnen mit den AWI Forschungsflugzeugen *Polar 5* und *Polar 6* geben.

Wissenschaftlich wird das gekoppelte Arktische Klimasystem während der einjährigen Expedition PS122 untersucht. Zu den Komponenten des Klimasystems zählen Atmosphäre, Meereis, Ozean, Bio-Geochemie und Ökosystem. Diese Komponenten werden einzeln betrachtet, aber auch deren Wechselwirkung untereinander sollen untersucht werden. Erstmalig ist es möglich, die Prozesse in der Arktis ganzjährig und auch im Winter zu untersuchen. Dies ist von enormer Wichtigkeit, denn die Prozesse sind bisher nicht ausreichend verstanden. Auch gibt es Lücken im Verständnis darüber, wie die sich ändernden Meereisbedingungen sich auf das Klima in der Arktis auswirken und auch regional und global das Wetter und Klima und deren Änderungen beeinflussen.

Der Mangel an Beobachtungsdaten in der Arktis, insbesondere im Winter steht dem ausreichenden Prozessverständnis im Wege. Dies resultiert in einer unzureichenden Repräsentation des Arktischen Klimasystems in den Wettervorhersagemodellen und den Klimaprognosen. Langfristig sollen die bei MOSAiC gewonnenen Daten dazu beitragen, die Modelle auf lokaler, regionaler und globaler Skale zu verbessen und Vorhersagen und Prognosen zuverlässiger zu gestalten.

Um dies zu bewerkstelligen, wird in MOSAiC darauf gesetzt, dass Messungen möglichst für das gesamte Untersuchungsjahr Herbst 2019 bis Herbst 2020 kontinuierlich durchgeführt werden und dies mit bereits erprobten Messmethoden und Instrumenten. Somit wird die Physik des Meereises (siehe Kapitel 4) mit der Formation im Herbst/Winter und während der Schmelzperiode im Sommer untersucht. Auch sind Drift und Deformationen interessante Faktoren des Meereises. Die Messungen finden teils *in-situ* und teils mit Hilfe von Fernerkundungsinstrumenten und Satelliten statt (siehe Kapitel 8). Die Prozesse im Meereis, wie zum Beispiel die Bildung von Schmelztümpeln und eisfreien Rinnen (Leads) und die damit verbundenen geänderten Wärme- und Impulsbilanzen, beeinflussen die Grenzschicht der Atmosphäre und im Ozean und haben Auswirkungen auf kleinskalige Prozesse wie Energie- und Impulsaustausch. Weitere wichtige Komponenten zur Untersuchung der Atmosphäre (siehe Kapitel 3) sind die Wolken- und Strahlungsprozesse und die Zusammenwirkung mit Aerosolen und die Bildung von Niederschlag. Im Ozean (siehe Kapitel 5) werden Salzgehalt und Temperatur gemessen sowie die vertikalen Austauschprozesse und die Bildung von Frischwasserreservoiren untersucht. Erstmalig ist es möglich, die Dynamik des Arktischen Ökosystems (siehe Kapitel 7) und Populationen in Ozean und Eis zu beobachten. Die Wissenschaftler, die das Ökosystem untersuchen, werden Proben im Ozean, Meereis und in den Schmelztümpeln sammeln. Die Biogeochemischen Prozesse (siehe Kapitel 6) finden im Ozean und im Meereis statt und die dabei erzeugten Stoffe gelangen in die Atmosphäre. Dort interagieren sie mit Aerosolen und beeinflussen die Wolkenbildung.

Diese kurze Zusammenfassung verdeutlicht bereits die Komplexität jeder einzelnen Komponente des Klimasystems, und es wird eine enorme Herausforderung sein, die Wechselwirkungen zu untersuchen, um ein besseres Verständnis für das gekoppelte Arktische Klimasystem zu erlangen.

Unterstützt und ergänzt werden die Messungen im zentralen Observatorium und im dezentralen Messnetzwerk durch die bereits erwähnten Flugzeugkampagnen, Satellitendaten und Simulationen mit verschiedenen Wetter- und Klimamodellen. Weiterhin sind koordinierte Messungen an arktischen Landstationen wie Ny-Ålesund und Station Nord während des gesamten Zeitraums von PS122 vorgesehen.

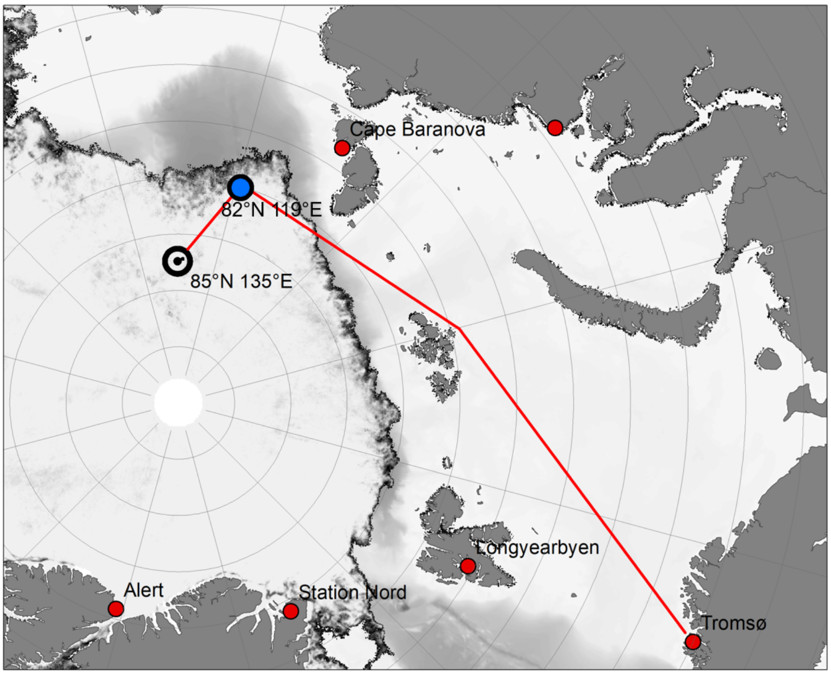

Fig. 1.1: Planned cruise (red line) track of Polarstern and Akademik Fedorov from Tromsø to the start point (black dot, 85°N and 135°E) for the search of a suitable ice floe for MOSAiC via the 82°N and 119°E where the mooring from Verena Schlindwein (DE.AWI) has to be picked up (blue-black dot). (Fig.: T. Krumpen (DE.AWI))

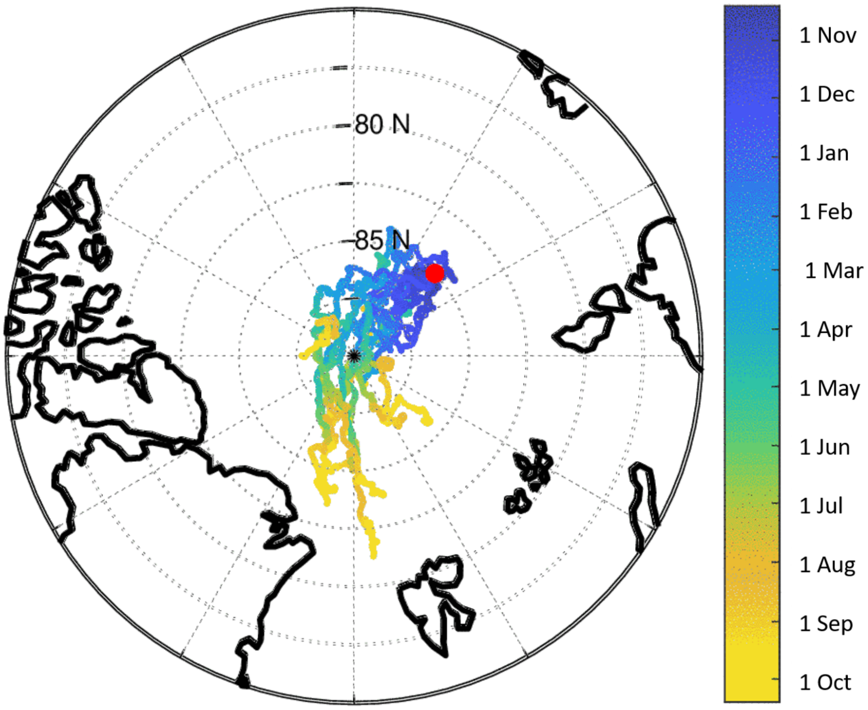

Fig. 1.2: Drift trajectories for the selected starting position (red dot, 85°N and 135°E) calculated for the years 2005 to 2017 assuming a start of the drift on October 15th. Colors represent the months of the drift. (Simulations: T. Krumpen (DE.AWI), Fig.: I. Woltmann and H. Deckelmann (DE.AWI))

SUMMARY AND ITINERARY

M. Rex (DE.AWI)

MOSAiC (Multidisciplinary Drifting Observatory of the Study of Arctic Climate) is *Polarstern* expedition PS122 and will start on September 20th 2019 in Tromsø (Norwegian). PS122 is a year-around expedition in the central Arctic Ocean and is devided into six legs (PS122/1 – PS122/6). The expedition will finish on October 14th 2020 in Bremerhaven.

During the beginning of PS122 the Russian research icebreaker *Akademik Fedorov* from the Arctic and Antarctic Research Institute (AARI) will join *Polarstern*. *Akademik Fedorov* will depart, too, on September 20th 2019 in Tromsø shortly after *Polarstern* will have left the port. Both ships will travel together towards the ice edge and through the ice and search for an adequate ice floe. As part of the journey the four moorings of Vera Schlindwein (DE.AWI) that are located in the area 82°N and 119°E will need to be collected (blue-black dot in Fig. 1.1). After eight days of travelling it is planned to arrive at 85°N and 135°E, the start point area where the search will take place to find the MOSAiC ice floe. The search is supported by satellites, sea ice forecasting and scientific experts on *Polarstern* and *Akademik Fedorov*. Within 5 days a suitable ice floe should have been found for docking planned on October 4th and will start with the set-up of the instruments on the ice floe. Ideally, the floe will be available for the whole year of the MOSAiC expedition and serve, together with *Polarstern*, as the Central Observatory (further information about the Central Observatory can be found in Chapter 2.1 (Ice Camp) and Chapter 2.2 (*Polarstern*). *Polarstern* will move together with the ice floe, following the natural drift of the sea ice, nearby the Pole towards the Fram-Strait. Fig. 1.2 shows the drift trajectories for the selected start point 85°N and 135°E with a start date of October 15th for the years 2005 to 2017. The still open water around *Polarstern* will freeze during the winter season and will provide the opportunity to analyze multi-year sea ice and newly formed sea ice. On October 14th 2019, the standard operations and observations will start.

During the set-up of the Central Observatory, *Akademik Fedorov* will bring out the Distributed Network stations that are located on ice floes up to 50 km away from *Polarstern* (further information about the Distributed Network can be found in Chapter 2.3). After building the Distributed Network, *Akademik Fedorov* is planned to travel back to *Polarstern* for refueling and exchange of scientists on October 15th and 16th, before sailing back to Tromsø and calling on the port on October 31st.

The six cruise legs of MOSAiC are accompanied with resupply cruises with icebreakers provided by MOSAiC partners. These cruises deliver food and fuel and exchange scientists and crew. The resupply between PS122/1 and PS122/2 (mid-December 2019) and between PS122/2 and PS122/3 (mid-February 2020) will be performed with the commercial Russian icebreaker *Admiral Makarov* provided from Rosmorport. During spring, when the sea ice has its largest extend and is at its thickest, *Polarstern* cannot be reached by an icebreaker and therefore, aircrafts will be used to exchange scientists and crew between PS122/3 and PS122/4 (mid-April 2020). It is not possible to supply *Polarstern* with fuel and food at this stage of the expedition. For the supply and the exchange of personnel between PS122/4 and PS122/5 (mid-June 2020) and PS122/5 and PS122/6 (mid-August 2020), research icebreaker from Sweden (*Oden*) and China (*Xuelong II*) will be available.

Campaigns with the AWI research aircrafts *Polar 5* and *Polar 6* in spring and summer 2020 will provide further measurements and enlarge the amount of data gained form the Central Observatory and the Distributed Network.

During the year-around MOSAiC expedition PS122 the coupled Arctic Climate System will be analyzed scientifically. The components of the climate systems are atmosphere, sea ice, ocean, bio-geochemistry and ecosystem that will be investigated in detail as well as the interactions between all these disciplines. For the first time, it will be possible to analyze the processes in the Arctic for a whole year, including the winter season. It is highly important to understand the climate processes taking place in the Arctic and the impact of the changing sea ice and climate conditions on the regional and global climate.

The lack of observational data in the Arctic, especially in winter, hamper a better understanding of the climate relevant processes leading to an insufficient representation of the Arctic climate system in weather prediction models and climate projections. The overarching and long-term goal of MOSAiC is to use the gained data to improve climate models in a local, regional and climate scale and to obtain more reliable forecasts and projections.

To achieve this, measurements should be done continuously throughout the whole year of the expedition from autumn 2019 to autumn 2020 with proven and well-known measurement techniques and instruments. The physical processes and properties of the sea ice (see Chapter 4), its formation in autumn and winter and the melting during summer will be analyzed. In addition, drift and deformation will be observed. This will be done with *in-situ* measurements and with remote sensing instruments and techniques (see Chapter 8). The generation of leads and melt ponds and the related changes in heat balance and momentum fluxes have an influence on the boundary layer of the atmosphere and the ocean. Further important components of the atmospheric processes (see Chapter 3) are cloud and radiation and the interaction with aerosols and formation of precipitation. The oceanic (see Chapter 5) environment will be analyzed concerning its salinity and temperature as well as its vertical structure and exchange processes and the development of fresh water reservoirs. For the first time, it is possible to observe the dynamic of the Arctic ecosystem (see Chapter 7), including the population in ocean and ice. Scientists will sample the ocean, the sea ice, leads and melt ponds. The bio-geochemical processes (see Chapter 6) take place in the ocean and sea ice and generated substances enter the atmosphere where they interact with aerosols and influence the cloud formation.

This short summary illustrates the complexity of each of these climate relevant components and therefore it is a tremendous challenge to analyze the interaction and achieve a better understanding of the coupled Arctic climate system.

The measurements in the Central Observatory and the Distributed Network will be supported and complemented by the already mentioned aircraft campaigns, the satellite data and simulations with several weather and climate models. In addition, coordinated measurements at the land-based stations in the Arctic like Ny-Ålesund and Station Nord will be performed during the whole period of PS122.

2. GENERAL SET-UP

The main Ice Camp and *Polarstern* will build the Central Observatory and are surrounded by the Distributed Network. Fig. 2.1 gives a general impression how the three components link together with smooth transitions as one observational network: Ice Camp (Chapter 2.1), *Polarstern* (Chapter 2.2), and Distributed Network (Chapter 2.3).

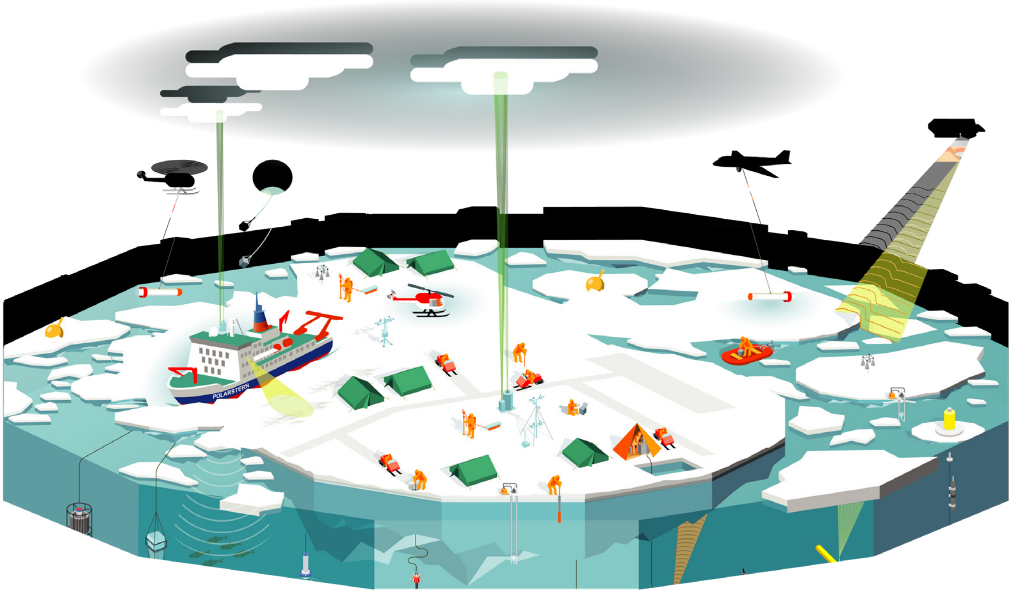

Fig 2.1: Illustration of the Central Observatory, consisting of the main Ice Camp and Polarstern anchored to the floe. The Ice Camp will host most installations and measurement sites of MOSAiC and is surrounded by additional floes and instruments of the Distributed Network. Beyond surface and ice tethered installations, the illustration shows airborne, satellite, under-ice instruments and methods.

2.1 Ice Camp

M. Nicolaus (DE.AWI), M. Shupe (EDU.CU), V. Mohaupt (DE.AWI), B. Rabe (DE.AWI), G. Spreen (DE.UNI-Bremen)

The Ice Camp is the central element of all snow and sea ice work and its interfaces to the atmosphere and the ocean. Except direct and remote sensing observations from *Polarstern*, all instruments are installed in the Ice Camp and most *in-situ* measurements are performed directly there on, in, and under the ice. The Ice Camp is accessible through a gangway from *Polarstern* whenever needed. Fig. 2.2 shows a conceptual and idealized map of all installations on the Ice Camp (status summer 2019 with ongoing updates). The area directly adjacent to the vessel will be used for logistics, tests, preparations, and leisure time. Beyond this, a network of defined walk and drive ways will be established using flags connecting the different measurement sites (dark brown lines). The main “highway” will contain four main power and data lines (black and light brown lines) of approx. 600 m length each, connecting the main measurement sites (Met City, Ocean City, ROV City and Remote Sensing City) to *Polarstern*. Additional connections will allow power supply to selected additional instruments. These main sites are described below. They will make use of the installation of semi-permanent huts on the ice as a base of operations and shelter for personnel. In addition, many designated observation sites will be defined to allow full annual observations with minimal impacts from previous observations and movements. All these sites are planned within a safety zone of 700 m around *Polarstern* (see working procedures below).

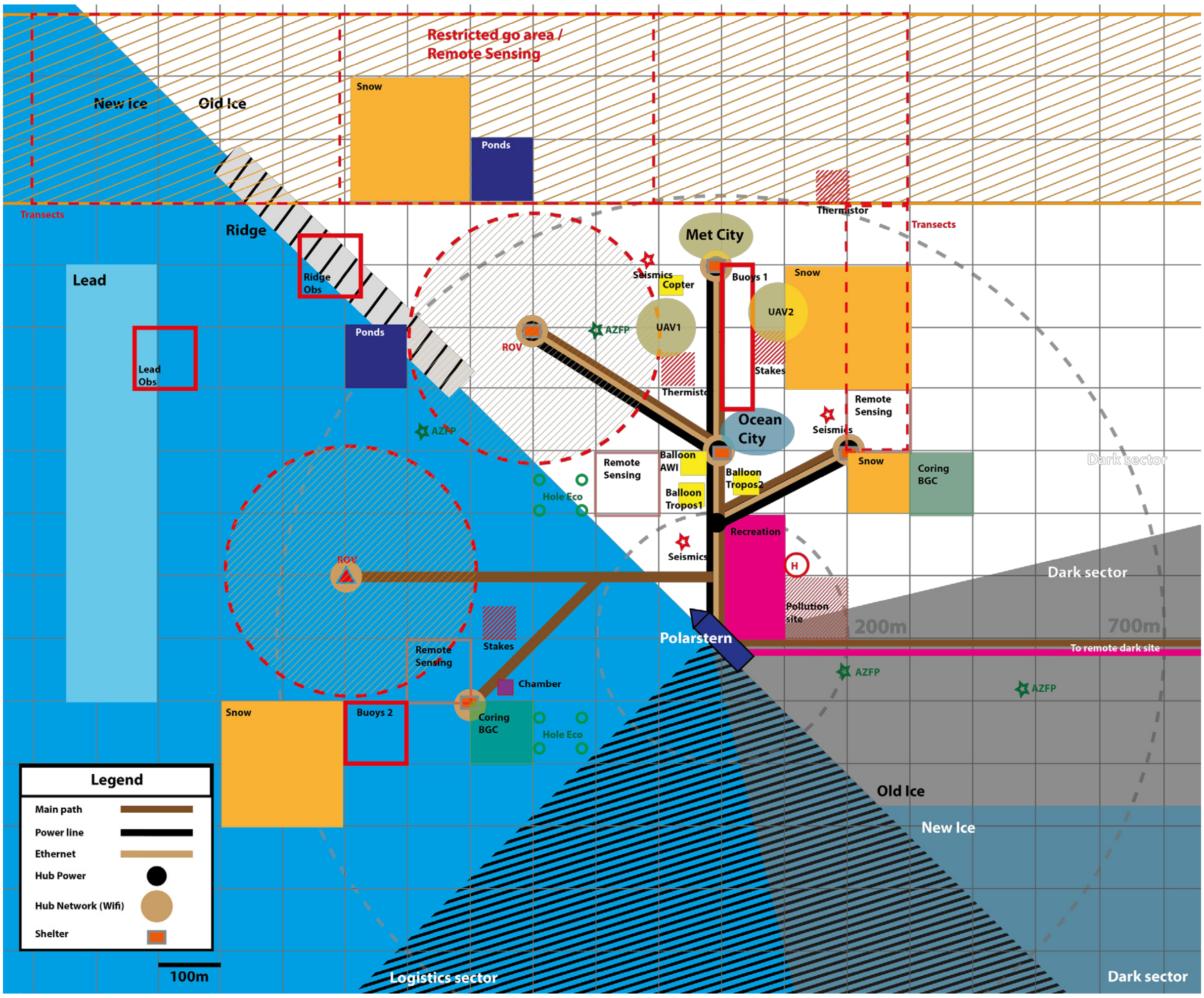

Fig. 2.2: Conceptual map of the main Ice Camp with all main installations

Initial Setup

Once arriving at the selected ice floe, *Polarstern* will anchor with its port side to the ice and the Ice Camp will be established. After initial surveys and planning the local coordinate system will be initialized (see below) and all main installations will be set up: Power and data lines, pathways, Shelters, main structures. In a second step, all sampling sites and larger instrumentation will be installed and allocated: Snow and ice sites, stakes, eco holes, additional masts, balloon tents, etc. Only then the routine of scientific work will start.

Ice types and sectors

The Ice Camp will grow from the initial ice floe when arriving (e.g. white and grey areas in Fig. 2.2) including new and more deformed ice types over time (e.g. bluish areas in Fig. 2.2). For obvious reasons, the dimensions, shape, ice types, ice patches of the initial Ice Camp cannot be foreseen, hence the idealized map in Fig. 2.2. has to be adapted to the ice conditions upon arrival. Parts of the scientific programme will depend on specific ice types like pressure ridges, leads, new and thin ice. This work will be conducted where and whenever these ice types are available. Some work will most likely not start in the very beginning of the drift. As a consequence, also some parts of the Ice Camp will only be installed over time (e.g. on the new ice, bluish colors in Fig. 2.2).

Beyond the main part of the Ice Camp (mostly forward and starboard of *Polarstern*), parts of the camp will be considered a “dark sector”, reducing artificial lights to a minimum (dark grey areas). A “logistics sector” will be defined in order to allow logistical operations during the re-supplies with minimal impact on the ongoing measurement programme and installations.

Met City

Met City will be located at the end of the main power line extending from *Polarstern* and will be occupied primarily by atmospheric measurements with additional observations related to other disciplines. The Met Hut will be the single central structure for Met City, providing shelter, the power connection, and the network connection. Surrounding the Met Hut various installations are planned. At the farthest point from *Polarstern* there will be a 12 m met tower with a 30 m met mast installed nearby, both for measuring low-level atmospheric structure, surface energy fluxes, atmospheric particles, and surface gas fluxes. These measurements will be performed at the farthest point from *Polarstern* and other infrastructure to minimize adverse impacts on surface turbulence measurements. Near the Met Hut you will find suites of instruments for measuring all components of the surface radiation budget and for measuring precipitation in various ways. These measurement regions will have surrounding no-go zones to minimize obstructions or interference of the measurements. Wind lidar and sodar instruments will be installed for making atmospheric wind profile measurements, and the wind lidar will be oriented in a way to operate synergistically with a similar lidar installed on the P-deck of *Polarstern* to help in creating a virtual wind profile. Multiple buoys will be installed in Met City, including an Autonomous Ocean Flux Buoy with sonar, an Ice Mass Balance buoy, and a temperature chain. Met City will also be an operational hub for surface scanning lidar measurements. Near Met City, but located somewhat closer to *Polarstern* a seasonal tent shelter will be set up to support unmanned aircraft operations. These aircraft operations require dedicated space for aircraft take-off and landing, as well as clear airspace access to the ice and snow beyond Met City. While some of the systems operated at Met City, particularly the buoys, are intended to operate semi-autonomously, many of the instruments will be monitored and maintained on a daily basis. The unmanned aircraft operations will occur when conditions allow.

Ocean City

Ocean City is the main access point to the ocean directly from the Ice Camp. The main feature of Ocean City is a shelter (Weatherhaven tent) with a protected hole through the ice and two winch system to run various instrumentation and nets. The site is also an access point for power and network (LAN/WIFI). In the Weatherhaven, physical, biological, geochemical oceanography and ecology work will be performed on a regular basis. The winch /rosette combination will allow retrieval of water samples, which may be processed to very limited degree in the Weatherhaven before transportation to *Polarstern*. Particularly the work from the ice allows studies of the uppermost ocean (0-10 m) that is disturbed at the main winch site of *Polarstern*. At Ocean City, ice and water conditions are mostly undisturbed and also interface processes may be studied. Additional autonomous instruments are permanently installed in Ocean City, including clusters to measure ocean turbulence and current velocity.

ROV City

ROV City will consist of two shelters, one for the ROV's (Remotely Operated Vehicle) electronics and one protecting the access hole to the ice. Around these installations, a region of 200 m radius will be protected from surface and under-ice installations and activities in order to maintain pristine snow and ice conditions. Only orientation aids and a local positioning system for the ROV will be installed under the sea ice. From this base station, the ROV system will be operated twice a week for surveys and sampling of water and ice in the uppermost 100 m of the ocean. A second ROV site / city is planned on the new ice forming adjacent to the original ice floe.

Remote Sensing City

There will be one main Remote Sensing site in the Ice Camp with a hut that provides shelter, network access, and power supply (upper right “Remote Sensing” area next to power line in Fig. 2.2). Instrumentation for evaluation and development of satellite remote sensing methods will be deployed within a radius of 100 m next to the hut (see also Section 8). The “Ietthus” hut (provided by NPI, Tromsø) is 2.3 x 2.3 m inside and on skies. The hut can be towed by Skidoos. The Remote Sensing site will be moved every 2 to 3 weeks. This is necessary to avoid non-natural snow accumulation in front of the remote sensing instruments and to measure different ice types. During this process, the hut and all instrumentations will be moved along the power line. Depending on the situation on the floe the Remote Sensing site will either be moved in steps along the power line towards the main power line closer to the ship (see Fig. 2.2) or back and forth between 2-3 sites along the power line. When the new ice is stable enough for instrument deployment or when a significantly different ice type is identified within Ice Camp the remote sensing instruments will be moved to those sites (see the other two “Remote Sensing” areas in Fig. 2.2) for limited time periods. However, no power will be available at those secondary sites and instruments have to run on batteries or generators. It is of critical importance that all remote sensing measurements are accompanied by extensive snow and ice physical measurements. Thus, the Remote Sensing site will be located next to snow sampling and ice coring sites (Fig. 2.2).

Distributed installations

Beyond the “Cities” many installations and sampling sites will be established in the Ice Camp, covering various snow and ice conditions. Large areas will be reserved for snow pit and snow sampling work (e.g. 3 to 5 sites of 100x100 m or 200x200 m each). Fields of larger size are (500x500 m) needed for sea ice coring and sampling. One field of each type will be located in the “dark zone” and will be one of the main time series fields for *in-situ* snow and ice work. Other snow and ice fields are co-located with the remote sensing and ROV measurements, while partly those fields will be at different sites, but representing most similar snow and ice conditions.

Buoys, such as also installed in the Distributed Network will also be deployed in the Ice Camp to monitor the atmosphere, snow, ice, ocean conditions there and to obtain comparable data sets to those from the remote sites. Beyond buoys that transmit their data via satellite link, a large suite of autonomous instruments is deployed which require regular maintenance (sensor cleaning, data checks, battery supply, etc.). Fields of thermistor strings, hot wires and ablation stakes are installed for snow and ice monitoring.

Deployment sites for ecological and chemical sensors and incubation experiments are selected and regularly visited and maintained. Sediment traps, zooplankton profilers, flux chambers and nets are installed for various time spans (from days to seasons).

Surface transects will be defined for repeated measurements of snow and ice properties along the same transect. Theses transects are partly co-located with according sampling sites, but will also pass along protected areas, which will remain undisturbed for airborne surveys and work late into the melting season.

Runway and airborne sites

Once ice conditions allow, a runway will be prepared on level sea ice (refrozen lead) to enable the landing and take-off of polar aircrafts of type DC3. This runway is essential to enable the close connection of various airborne activities around the main camp and as an emergency link to land. The position will depend on local ice conditions, but a distance of less than 3km to the ship is the goal. Runway preparation will be performed by plowing and leveling the snow/ice surface using a Pistenbully.

Beyond this remote and major runway, the Ice Camp has designated areas for further airborne activities. Two sites are selected for operations of tethered balloons, one area will be used as a hub for drones and fixed wing small aircrafts. Helicopter operations will be performed directly from *Polarstern* (see Chapter 2.2).

Working procedures and principles

The camp will be planned for walking? on a culture of walking: Snow scooters will be used for transportation of equipment, but not for general travel of personnel on the ice. We will also try to keep the camp as “light” as possible, with the smallest possible footprint on the ice. This will reduce our own impact on the surface to a minimum and also ease evacuation in case of fracturing and melting of the floe.

For safety reasons, 3 zones are defined, all representing specific safety regulations. The main working area (Zone 1) reaches to approx. 700 m around *Polarstern*. The aim is to enable safe work during standard working hours in this zone without additional individual protection against polar bears. Zone 2 will reach up to 3 nm and will also allow daily ground-based work, but with additional safety means and in limited group sizes. Zone 3 will be all work beyond 3 nm and will have more specific regulations and will mostly be accessed by helicopter. Work in all 3 zones will be scheduled daily in order to optimize scientific needs and logistic resources and safety. Work on the ice will be possible, weather conditions permitting, at all times. However, the main daily routines will be worked on during main working hours, when also Zone 1 will be generally protected from polar bears.

Floe Navi

In order to enable and ease orientation on the floe and to document all installations and measurements on the drifting sea ice, a local coordinate system that is fixed to the Ice Camp is defined. Working with this coordinate system in addition to the geographic positions will allow us to relate measurements with respect to their relative position to each other. To do so, the new Floe Navi system was developed, defining and maintaining a x-y-coordinate system (in meters) fixed to the floe. A set of fixed base stations will communicate their positions constantly via the AIS (Automatic Identification System) technology and mobile stations will then be able to calculate and record their position in these x-y coordinates. Finally, a user interface will be used to register all kinds of measurements and link them directly into the general station book and scientific documentation. The system is expected to maintain the coordinate system also when the ice floe is breaking and re-freezing.

2.2 Polarstern

M. Nicolaus (DE.AWI), M. Shupe (EDU.CU), V. Mohaupt (DE.AWI), A. Fong (DE.AWI)

Polarstern is the central element and has various roles during MOSAiC: It is the home and base of all MOSAiC participants during the drift, it hosts all laboratories, offices and workshops and is used for staging all installations. It is the hub for all scientific and logistical helicopter operations, it hosts the huge suite of (under way) instruments and sensors, it stores and operates all additional measurement containers and laboratories, and stores all data. All installations consider the year-long perspective of all measurements and work on board.

From a scientific point, major changes and additions that were not part of the usual *Polarstern* expeditions, had to be realized to enable the interdisciplinary programme of MOSAiC and included

- Installation of the bow crane for atmospheric measurements in front of the ship
- Installation of (mostly atmospheric) laboratory containers on the bow on 2 stories, including an additional walk way between the containers
- Reinforcement of lower P-deck to support a laboratory container
- Installation of a new winch system for the moon pool to access the water column
- Installation of various sensors and instruments on the decks and around the railing, including various anchor points
- Installation of new supply facilities (e.g. liquid nitrogen, milli-q water, ..)
- Re-arrangements of installations in all labs to host the complex MOSAiC instruments
- Extensions of server and network hardware
- Advanced winterizing of the ship for the harsh winter conditions
- Optimizing available space on board in many areas (cabins, labs, storage, etc)

Through the long period of the drift, when the ship may be considered stationary with respect to the ice and (to some degree) to the water, further precautions were taken to reduce the impact of the vessel and the scientific party itself on the measurements:

- A new system for grey water handling was installed
- Unnecessary illumination of the surrounding of the vessel is to be avoided, in particular into the aft section, which is considered the dark sector (Fig. 2.2)
- The exhaust of *Polarstern* is reduced to the minimum necessary for the maintenance of the ship, including the power supply and the heating
- Burning of fuel (scooters, generators, heaters) on the ice is reduced to a minimum and times and positions of operations are documented

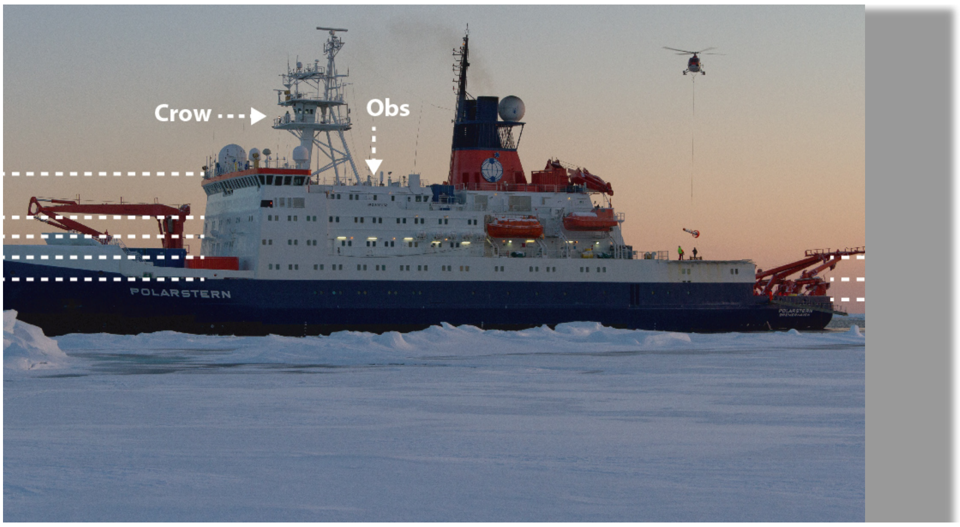

Fig. 2.3: Polarstern with deck names

Laboratory arrangements

Prior to the drift, all labs and rooms had been assigned to specific tasks and teams All labs and rooms on board are assigned to specific tasks and teams prior to the drift. This plan is based on good experience from previous interdisciplinary expeditions and their use of ship space, but also considers the particular requirements of long-term observations for MOSAiC. Specific assignments are:

- The large wet lab on E-deck will be used for all teams for staging field equipment and other logistical needs.
- All dry labs will be distributed to the different teams, aiming for consistency over all legs.
- Chemical and biological labs, as well as an isotope container are available through the entire experiment.
- Most labs are on E-Deck (see Fig. 2.4), but additional rooms are available on A-deck, mostly used in connection to atmospheric and remote sensing or airborne related work.

Installations on board

In addition to the installations in laboratories in the ship, different kinds of instrumentation are installed at suitable positions outside on deck and along the railing of *Polarstern*. Most prominent are opportunities to use the P-deck (observational deck) and the crow's nest for installations that require a view of the sky or access to higher altitudes:

- Antennas for remote sensing applications in different frequencies and modes
- Radar for sea ice movement and deformation
- Radar, lidar and radiometer systems and antennas for atmospheric studies
- Cameras, visible and infrared
- Air samplers and pumps for aerosol studies
- Meteorological sensors and position systems beyond the standard configurations
- Different communication systems with remote installations

In view of all the complex instrumentation of *Polarstern* and the Ice Camp, all acoustic, optical, and microwave devices are registered with respect to potential interference, because it has to be expected that certain instruments will need to be scheduled for transmission / recording in order to minimize interference.

Container and freight arrangements

In addition to the existing laboratories onboard *Polarstern*, a number of laboratory and storage containers are needed to accommodate the various needs of all teams on board. These containers include

- Facilities for atmospheric measurements with unobstructed views of the sky
- Additional workshops and storage containers at different temperatures (incl. freezer lab)
- Wet and laboratories for biological and geochemical work (incl. an isotope lab)
- Refrigerators for sample storage
- Storage containers at room or outside temperature

Other large items, such as the two Pistenbullys and the container sleds have dedicated storage spaces, mostly for transit and later recovery.

Major coordination has been ongoing to plan all freight storage and handling, because all 6 legs will have to be planned ahead and only limited exchange is possible during the rotations. As a consequence, many more and diverse instrumentation and cargo need to be handled in the given limited space. Freight is pre-sorted in a 2-weeks' preparation phase in Tromsø (port of departure) to map all participants' needs to the available storage and labs with given temperatures and access over time. Sample storage has to be organized, in most cases, for the entire year.

Access to sea ice and ocean

Access to sea ice is given from the starboard side of *Polarstern* via a new wider and extended gangway. All gear can be lifted to the main Ice Camp on starboard with the existing cranes. This access will be granted for all times, whenever necessary and weather permitting. Directly linked to the access to the ice and the work on ice, a comprehensive catalogue of advanced safety means has been established for MOSAiC. This includes an advanced supervision of ice access and movements of groups on the ice as well as new routines for health and environment during all work on board and on the ice.

Access to the water column next to *Polarstern* will be given at the usual position. For this, a hole through the ice will be prepared and maintained in accordance to the weekly schedule (see Section 2.1 Ice Camp). This hole will mainly be used for deploying the CTD rosette, *in-situ* pumps and different kinds of nets. To some degree, the extended functionality of the moon pool in the ship may support this work, in particular when difficult ice conditions do not allow the preparation of the ice hole next to the ship.

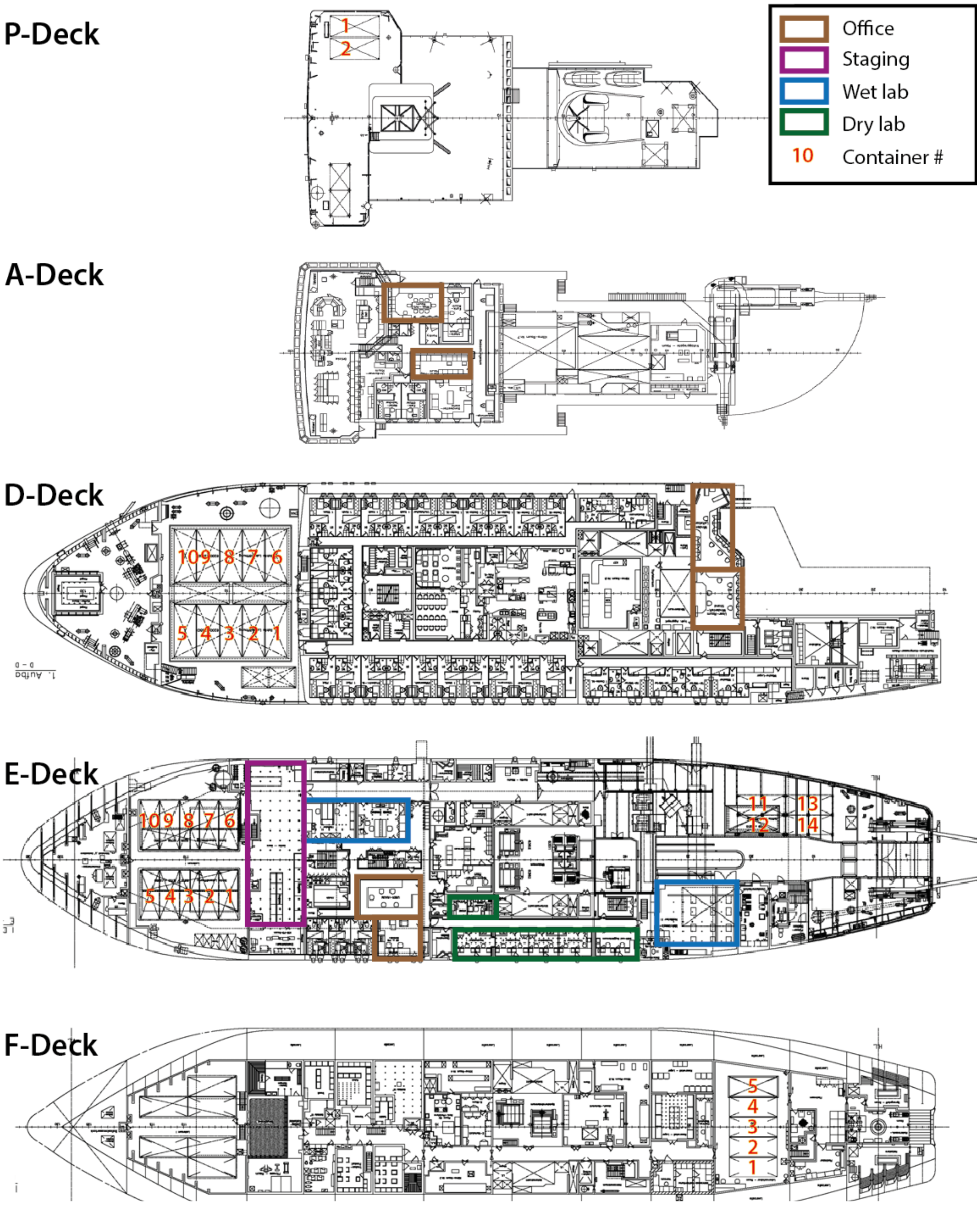

Fig. 2.4: Positions of scientific containers (laboratories, storage, workshops) and laboratories on the different decks of Polarstern. "Offices" may also include computers and electronics in a wider sense (e.g. registration units or instruments). P-Deck refers to the uppermost deck above the vessel's bridge.

2.3 Distributed Network

B. Rabe (DE.AWI), M. Nicolaus (DE.AWI), M. Shupe (EDU.CU), T. Stanton (EDU.NPS), M. Hoppmann (DE.AWI), T. Krumpen (DE.AWI), C. Cox (EDU.CU, *Akademik Fedorov* only), S. Archer (ORG.BIGELOW), L. Wang (CN.BNU), O. Persson (EDU.CU), R. Lei (CN.PRIC), G. Zuo (CN.PRIC, *Akademik Fedorov* only), H. Wang (CN.ZJU, *Akademik Fedorov* only), N. Kolabutin (RU.AARI), A. Nubom (RU.AARI), J. Haapala (FI.FMI), J. Belter (DE.AWI, *Akademik Fedorov* only), J. Rohde (DE.AWI, *Akademik Fedorov* only), Raphael (EDU.DARTMOUTH), M. Tsamados (COM.UCL, *Akademik Fedorov* only), D. Watkins (EDU.ORSU, *Akademik Fedorov* only), Y.-C. Fang (DE.AWI), H. He (CN.SIO), L. Lin (CN.SIO, *Akademik Fedorov* only), T. Li (CN.OUC), J. Zhu (CN.OUC, *Akademik Fedorov* only), B. Shaw (EDU.NPS, *Akademik Fedorov* only), C. Basque (EDU.WHOI, *Akademik Fedorov* only), A. Davies (EDU.WHOI, *Akademik Fedorov* only), X. Ma (CN.MNR, *Akademik Fedorov* only), J. Hutchings (EDU.ORSU), D. Perovich (EDU.DARTMOUTH), R. Krishfield (EDU.WHOI, not on board), J. Toole (EDU.WHOI, not on board), S. Cole (EDU.WHOI, not on board)

Overview

The Distributed Network of autonomous observing systems ("buoys") is made up of several sites on ice floes within about 40 km around *Polarstern* and the central Ice Camp (Central Observatory). These systems transmit data in near real-time via satellite (usually IRIDIUM) to land. The resulting observations will extend the manual and autonomous measurements in time and space around *Polarstern*.

Site and buoy types

There are three different types of sites, distinguished by the type of buoys:

- There are three L-sites with heavy buoy systems for atmospheric flux observations ("ASFS"), ocean fluxes ("AOFB"), ocean profilers in the upper ~800 m ("profilers"), ice-ocean biooptical properties and radiation ("IBOB"), ice mass balance ("IMB") and snow thickness ("snow"). The tentative layout of one of these sites is shown in Fig. 2.5.
- Nine M-sites will carry medium complexity buoys, including a subset of the following observations: continuous temperature and salinity at fixed depth in the upper ~100 m ("PGTS"), short ocean profilers in the upper ~ 200 m ("D-TOP"), ice mass balance ("IMB") and snow thickness ("snow"). One M-site, named "LM2", is located in the dark sector aft of *Polarstern* and may carry a large ocean profiler, similar to an L-site, as well as additional equipment that does not send data via satellite. The site "MF" will be located farthest from the Central Observatory to allow undisturbed snow measurements.
- Several GPS-only buoys (e.g. "SVP") will be deployed at the P-sites to obtain information about ice deformation and drift.

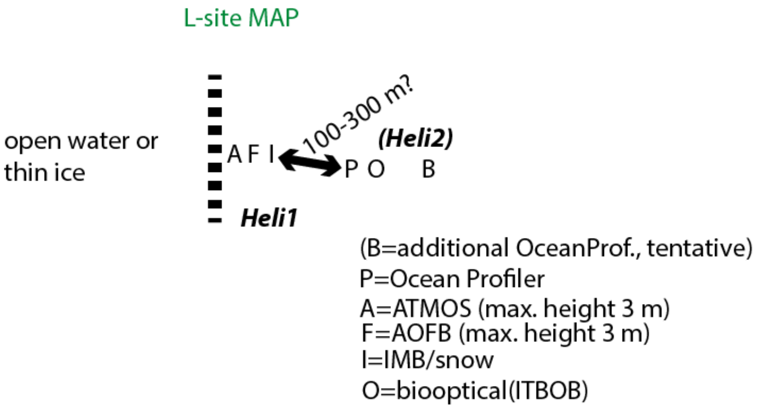

Fig 2.5: Proposed layout of an L-site with legend. Atmos = "ASFS"

Some of the M- and L-site will have additional IMB systems to obtain observations on the same ice floe and/or at different initial ice thicknesses. The initial (deployment) location of the sites relative to *Polarstern* ("PS") is shown schematically in Fig. 2.6. A subset of these buoys is also present in MET City in the Ice Camp (see 2.1). There will be temporary use of observing equipment in parts of the Distributed Network, at any of the sites and in other locations, such as leads (site Le in Fig. 2.6). Other locations in the Distributed Network may be visited opportunistically to obtain measurements undisturbed by the Central Observatory, but this activity will be limited by environmental conditions (e.g. light), logistics (transport) and safety. The layout in Fig. 2.6 is subject to ice conditions and logistical constraints during deployment. The ice drift and deformation is expected to lead to an asymmetric relocation of sites throughout the drift.

Initial Setup and ice types

Most of the buoy deployments will be realized during the initial setup phase of MOSAiC. During that time, the Russian icebreaker *Akademik Fedorov* will provide a platform to search for suitable ice floes, deploy large buoy systems by docking directly onto the floe of each L-site, and deploy the medium-sized buoys and the GPS-only buoys by MI-8 helicopter at locations away from the ship.

The ice floes will have to be carefully selected according to the design / type of buoys and the scientific aims of the autonomous measurements.

L-site should be thick first-year or multi-year ice, preferred with areas of ice thickness between 1-2 m for most of the heavy buoys. IMB and snow buoys may selectively be deployed on thinner ice; in particular, if multiple IMB are deployed at the same site. Fig. 2.5 shows that some of the buoys are to be deployed close to the edge of the floe, near open water / thin ice, e.g. the ASFS. On the other hand, some buoys do not require to be near open water or thin ice, so they would preferably be deployed 100-300 m into the ice floe to increase the chance of survival in deforming ice. The whole ice floe would preferably have ridges near the edges, although those should not obstruct the ASFS.

M-sites should preferably have similar thickness to the L-sites, but floes may be less substantial in extent and require less plan area for buoy deployment. However, they need to have room for a large helicopter (e.g. MI-8) to land safely.

Selected buoys or components of systems will be deployed in spring, once light conditions improve in late winter / spring; for example, sensors for radiative fluxes above and below the ice. These operations will be done from *Polarstern* using skidoos or helicopters.

Details of ice floe search are outlined in a separate "one-pager" document.

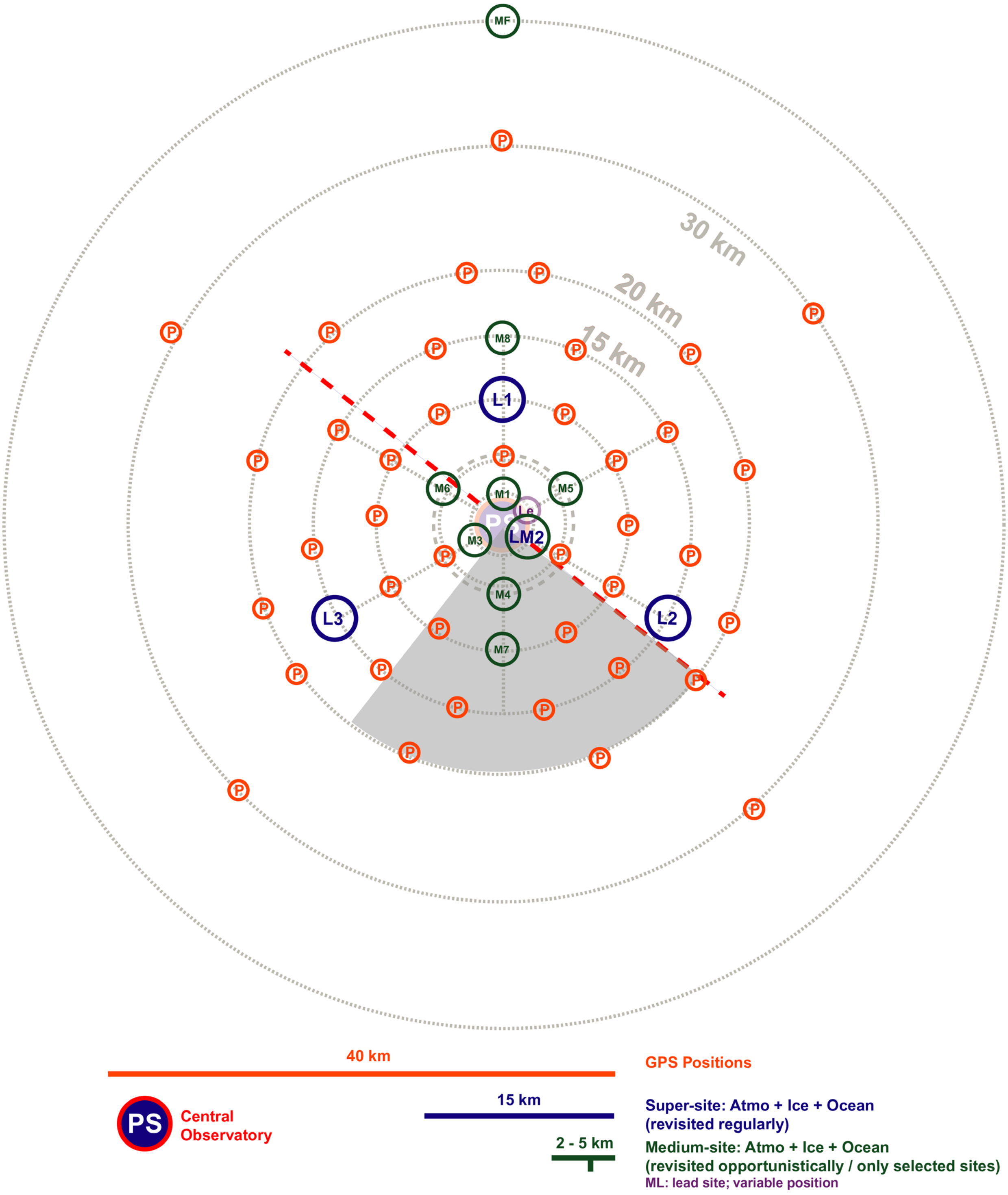

Fig 2.6: Conceptual map of the main sites in the Distributed Network, sorted by type of instrumentation. Le / ML is a hypothetical site, for temporary use to obtain observations around a lead.

Working procedures and principles

The L- and M-sites will be revisited to allow servicing of the buoys, to obtain calibration samples and for general work away from the Central Observatory.

Monthly visits are planned to service the ASFS and other buoys, take calibration samples for the IBOB and calibration profiles for the profiles at the L-sites. The visit will usually take 2-4 hours on-site.

The M-sites should be revisited at a similar frequency, if possible, to allow calibration profiles for the PGTS buoys. Those visits will typically require about 1 hour on-site.

If troubleshooting or more extensive work is needed on any malfunctioning buoy, time required on-site may be longer. This includes recovery / redeployment, in case normal buoy operation cannot be resumed by other means.

Further *in-situ* sampling and measurement activity may be combined with the above work at each site, potentially prolonging time on-site.

Any equipment required on-site will be transported by skidoo/sledge, ARGO or helicopter. Outside loads will usually not be required, except in cases of recovery / redeployment of large systems.

Due to limitations of flying and landing on the ice during darkness, remotely operated lights will be installed at all L-sites and selected M-sites, that are out of skidoo distance or close to the limit (at least 5 km away from the ship).

Approach of Polarstern by supply vessels

The navigation of supply vessels through the Distributed Network will require close communication between *Polarstern* and the supply vessel. Information about positions of sites, buoy locations transmitted via satellite to land and back to *Polarstern*, and high-resolution SAR images will be communicated to the supply vessel. The scientists and *Polarstern* crew on-board the supply vessel (exchange) will assist in relaying this information to the captain of the supply vessel. Radar reflectors are installed at all L- and M-sites to allow further locating the sites on the supply vessel's radar. As few buoys as possible will be installed in the "logistics sector", aft and portside of *Polarstern*. However, ice drift / deformation will likely relocate several sites into the sector throughout the drift. These procedures will be detailed further in a separate "one-pager" document.

2.4 General data management

All data that will be collected during the expedition on *Polarstern*, in the central observatory or in the distributed network will be stored in the MOSAiC Central Storage (MCS) on board of *Polarstern* and on land as soon as possible. PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) is the primary long-term archive for the MOSAiC data set. The usage and sharing of data from MOSAiC consortium members and release dates, is settled in the MOSAiC data policy (see Appendix A.4). Exceptions need to be documented in written agreements.

3. ATMOSPHERE

M. Rex (DE.AWI), M. Shupe (EDU.CU)

3.1 From the surface to the stratosphere: Characterization of the atmospheric column

M. Rex (DE.AWI), M. Maturilli (DE.AWI, not on board), A. Schulz (DE.AWI), J. Gräser (DE.AWI), S. Dahlke (DE.AWI), A. Sommerfeld (DE.AWI), R. Jaiser (DE.AWI), H. Deckelmann (DE.AWI), B. Segger (DE.AWI)

Objectives

By implementing mobile mast and different balloon platforms, we aim to observe thermodynamic, turbulence and trace gas parameters at the ice-atmosphere interface, in the planetary boundary layer, in the free troposphere and the lower stratosphere.

a) Turbulent energy fluxes over sea ice and over leads

The turbulent exchange within the Arctic atmospheric boundary layer (AABL) is not well understood. Models show a wide spread in the prediction of the turbulent fluxes due to both strong overestimation and underestimation of its magnitude, respectively, sometimes even within one model for different atmospheric conditions. The reasons for that are insufficient parametrizations of the turbulent exchange which are developed on the basis of a very limited number of datasets measured during short campaigns like SHEBA (Uttal et al., 2002). These datasets typically did not cover the full spectrum of atmospheric conditions, seasons or surface characteristics. Therefore, the parametrizations do not include all relevant processes or only in an insufficient way. Especially the studies of the turbulent exchange over open leads on sea ice in the high Arctic are very rare due to a very small number of campaigns like ALEX within AIDJEX (Andreas et al., 1979), LEADEX (Ruffieux et al., 1995) and STABLE (Tetzlaff et al., 2015).

The extraordinary opportunity during MOSAiC is the possibility to measure the turbulent exchange with the newest generation of *in-situ* turbulence sensors during a full annual cycle and for nearly all relevant surface characteristics. For that purpose, mobile eddy covariance towers will be installed at the edge of open leads and close to ridges on the sea ice, in such a way that the targeted areas are directly within the instruments' footprint. Additionally, a net radiometer will measure all four radiation components over the open water body during measurements at open leads completing the measurement of the surface energy balance.

Furthermore, pronounced changes in the surface characteristics like a change of thermal conditions (open leads, warm water) or ridges (high obstacles, strong friction) result in the development of internal boundary layers on the Lee side of the targeted area. Especially for thermal internal boundary layers (over open leads) both the height and the temporal evolution so far were very seldom observed resulting in a small number of data points and a wide spread (see e.g. Andreas et al., 1999). Therefore, a 10 m tower with an optical fibre cable (DTS system) measuring the air temperature every 60 cm (25 cm sampling length) and 5-10 s will be installed next to the mobile eddy covariance system for observing the temporal evolution of the thermal internal boundary layer.

b) Characterization of the planetary boundary layer over sea ice

The Arctic atmospheric boundary layer (AABL) is often a neutral, under high-pressure system influence or during polar night occasionally persistent strongly stable system. This results in both fast changing turbulent characteristics in near neutral conditions and strongly inhibited exchange within surface-based inversions under stable conditions. For the observation of state transitions and the small-scale turbulent exchange the thermodynamic structure of the AABL measurements are needed with high spatial and temporal resolution but also with high precision and accuracy. These requirements are fulfilled by the DTS technology. Operating a tethered balloon as carrier platform, a DTS fibre will be applied to register vertical temperature profiles from the ground to about 1,500 m. The measurements are extremely high resolved both in vertical space (60 cm physical, 25 cm sampling increment) and time (5-10 s), and will allow the analysis of the low frequency part of the turbulent spectrum of the temperature profile in time and space. This is the first time that a DTS system will be operated on a tethered balloon on regular basis.

In addition, several other instruments by other projects and institutions will occasionally be operated on the tethered balloon platform, including e.g. an optical particle sonde, an aerosol particle filter package, a turbulence sensor package. The combined measurements assure the close link to other projects and foster the joint analysis of other atmospheric topics.

c) Characterization of the free troposphere and lower stratosphere

An extensive balloon programme will operate from board *Polarstern*, reaching from upgraded weather balloons to sophisticated research sondes. The profiles obtained by radiosondes launched four times daily will directly support the on-site weather forecast during the expedition, while they further contribute to numerical weather forecast as observational input for data assimilation. Additional Arctic radiosondes are known to positively impact the performance of forecast systems (Yamazaki et al., 2015; Inoue et al., 2015) even in regions far from the Arctic (Sato et al., 2016; 2018). The atmospheric thermodynamic structure over sea ice was recorded by radiosondes during earlier campaigns like e.g. SHEBA (Uttal et al., 2002) or N-ICE2015 (Kayser et al., 2017) for other regions of the Arctic. Now, the atmospheric structure, moisture content, stability, ABL height, tropopause height and other features in the vertically resolved atmospheric column will be monitored in the Central Arctic for a complete annual cycle. Events of heat and moisture transport into the Arctic by intrusions or atmospheric rivers (Woods and Caballero, 2016; Nash et al., 2018) will be identified, and their impact on the local atmospheric structure analyzed. The combination with projects that focus on the observation of clouds and radiation will allow to focus on the transitions between radiatively clear and cloudy states (Stramler et al., 2011; Graham et al., 2017) and how these transitions impact the vertical stability and coupling within the atmospheric column. The radiosonde profiles retrieved during MOSAiC will be set into context with similar measurements at pan-Arctic land-based stations (e.g. Ny-Alesund, Utqiagvik/Barrow, and other IASOA stations) for studies of the advective connection between the inner and outer Arctic, and the role of the Arctic dome in these exchange processes.

Weekly ozone sonde profiles will characterize the ozone distribution in the tropo- and the stratosphere throughout the year. In winter and spring, they will be part of a potential pan-Arctic ozone sonde campaign (Match) with coordinated soundings at all Arctic ozone sonde stations (e.g. von der Gathen et al., 1995; Rex et al., 1997, 2004; Manney et al., 2011). The aim is to determine the ozone loss inside the polar vortex. We expect new Arctic record ozone losses due to record low temperature regimes in single winters within the future 10 to 20 years (e.g. Rex et al., 2006).

Water vapor is a chemically, physically, and radiatively active trace gas, and its distribution in the stratosphere determines significant climatic implications. The water vapor distribution in the Arctic stratosphere bares evidence for dynamical aspects on different scales, including the large-scale descending motion inside the polar vortex as well as filamentary structures at the vortex edge linked to Rossby wave activity (Maturilli et al., 2006). In the presence of very low temperatures, the sedimentation of polar stratospheric cloud (PSC) ice particles can lead to dehydration events (Maturilli and Dörnbrack, 2006; Khaykin et al., 2013). With our monthly balloon-borne cryogenic frostpoint hygrometer (CFH) measurements during MOSAiC we contribute to the assessment of the water vapour distribution in the Arctic stratosphere. The dual soundings with the Compact Optical Backscatter and AerosoL Detector (COBALD) during polar night will allow to identify PSC layers related to dehydration.

Work at sea

The sounding programme from board *Polarstern* will start as soon as airspace regulations permit this (out of the Russian sovereign territory).

During the ice camp period, a 9 m3-helium-filled tethered balloon (TB) with a maximum payload of 4 kg will be deployed at the ‚Ocean City' site on the ice. Stored in a hangar tent while not in use, it will reach an altitude of up to 1500 m during operation. Several instruments will be installed on the TB platform, including a simple meteorological package transmitting temperature, humidity, as well as wind and altitude information just below the balloon. In a continuous measurement mode, the balloon will be set up in a constant altitude for several hours, with the DTS fibre attached for the continuous high-resolution profiling of temperature. For scientific analysis, these measurements will be combined with e.g. the virtual tower for wind profile detection (Univ.Trier), to study turbulent energy fluxes in the lowermost part of the atmosphere. In the continuous measurement mode, an additional aerosol filter sampler (BAS) will be installed on the TB to collect aerosol particles in the atmospheric boundary layer. When operating the TB in profiling mode (ascent and descent of the balloon), a turbulence sensor (TROPOS) allowing calculation of dissipation rates, an optical particle counter (BAS), and potentially an ozone sonde (NOAA) will be attached to the carrier platform. Operation of the tethered balloon is contemplated under suitable weather conditions with less than 7 m/s of surface wind.

The mobile eddy covariance and DTS systems (10 m mast) will be installed at the ice edge of suitable open leads and borders of ridges depending on science board decision on event basis. The partly preassembled systems will be transported on sledges coupled on skidoos by the two AWI atmosphere team members. The installation and setup finalization will be done on site.

Preliminary (expected) results

- 6 hourly vertical profiles of temperature, humidity, wind speed, wind direction, and pressure from surface to about 30 km
- weekly vertical profiles of ozone partial pressure and number density
- monthly vertical profiles of stratospheric water vapor mixing ratio, combined with aerosol backscatter profiles during polar night conditions
- for mobile eddy covariance towers high resolution (20 Hz) time series data of all three wind components, sonic temperature, H_2O and CO_2 gas concentration for calculation of turbulent fluxes; preliminary fluxes available
- for mobile eddy covariance towers low resolution (depending on sensors response time several sec) time series data of relative humidity, air temperature, air pressure, shortwave radiation (in/out) and longwave radiation (in/out)
- for mobile DTS 10 mast vertical light backscatter profiles every 5-10 s (depending on the configuration); preliminary temperature profiles available
- vertical profiles of wind and temperature fluctuations (profiling operation with TROPOS turbulence sensor); preliminary dissipation rates only on demand
- for the DTS system on the balloon platform vertical light backscatter profiles up to 1500 m altitude every 5-10 s (depending on the configuration); preliminary temperature profiles available

Data management

All radiosonde data will be transmitted to the GTS in near real-time to assure their availability for numerical weather forecast. All sounding data (radiosonde, ozone sonde, CFH, COBALD) and according auxiliary measurements will be stored in the MCS on a daily basis. After each leg, the preliminary sounding data will be processed at the GRUAN Lead Centre in Lindenberg, Germany. The final sounding data will be made available via the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) according to the MOSAiC Data Policy.

The eddy covariance raw data, radiation data and DTS light backscatter profiles (incl. preliminary temperature profiles will be also stored in the MCS after each measurement period (one to several days). The final data processing of the turbulent fluxes and DTS temperature profiles will be conducted at the Alfred Wegener Institute in Potsdam, Germany (contact: Alexander Schulz, alexander.schulz@awi.de). Final data products will be published via PANGAEA data repository according to the MOSAiC Data Policy as well.

All data are handled, documented, archived and published following the MOSAiC data policy.

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3.2 Aerosol, clouds and radiation

R. Engelmann (DE.TROPOS), H. Griesche (DE.TROPOS), M. Radenz (DE.TROPOS), K. Hanbuch (DE.TROPOS), C. Pilz (DE.TROPOS), M. Lonardi (DE.Uni-Leipzig), A. Macke (DE.TROPOS), H. Kalesse (DE.Uni-Leipzig), J. Hofer (DE.TROPOS), D. Althausen (DE.TROPOS)

R. Neggers (DE.UNI-Köln, not on board), H. Siebert (DE.TROPOS, 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 the central Arctic 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. Most instruments are integrated in the container-based atmosphere observatory OCEANET.

b) Lidar measurements

Since more than 20 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 the OCEANET-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 depolarization is measured in order to discriminate between spherical and non-spherical particles, e.g. water clouds vs. ice clouds. The lidar is equipped with a measurement channel for atmospheric water-vapor, 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 PS122 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. Additionally, a dual-field-of-view polarization channel is included to be able to derive liquid-water-cloud properties such as droplet size and number concentration at the cloud base.

c) 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”), 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. 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. 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 PS122/4.

Work at sea

Upon arrival at the ice flow camp the container-based atmosphere observatory will be installed at the front-deck of *Polarstern*. Most measurements will be performed continuously during all six legs of MOSAiC. The following individual instruments are combined:

- Two multichannel microwave radiometers HATRPO and LHUMPRO. The instruments require calibration with liquid nitrogen approximately every three months.
- Total-sky imager for cloud structure measurements
- Multiwavelength polarization Raman lidar PollyXT
- Stabilized Cimel Aeronet sun photometer for aerosol and cloud optical thickness
- Standard meteorological data logging with extended radiation measurement equipment
- Parsivel-2 disdrometer for precipitation size and velocity.
- 2D video disdrometer for shape of precipitation particles
- CORAS for the measurement of spectral radiance from VIS to infrared.

Tethered balloon observations with multiple sensors are planned for PS122/4. A 90 m^3 Helium-filled balloon with a maximum payload of 20 kg will be deployed at the Met City to profile the ABL from the ground up to 1,500 m altitude. Several measurement units will be fixed at the balloon to study turbulent and radiative energy fluxes as well as aerosol and cloud microphysical properties. 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 the OCEANET container.

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.

Preliminary (expected) results

- 2d structure of the clear sky atmosphere and corresponding net radiation budget
- Horizontal structure of the cloud water path and its effect on the downwelling shortwave and longwave radiation
- Vertical structure of temperature and humidity as well as its variability for validation of satellite products
- Vertical profiles of tropospheric aerosols and their effect on radiation
- Near-surface aerosol size distributions and their physical and chemical compositions
- Vertical profiles of turbulence, aerosol and cloud microphysical properties as well as down- and upwelling solar and thermal radiative fluxes
- Precipitation amount, size, and shape at ground to obtain a link to ARM cloud-radar data
- Aerosol optical thickness

Data management

All final data will be stored at Pangea (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) after post-processing and careful quality checks. All data are handled, documented, archived and published following the MOSAiC data policy.

References

NONE.

3.3 DOE Atmospheric Radiation Measurement Program's Mobile Facility

M. Shupe (EDU.CU), H. Powers (GOV.ARM, not on board), D. Chu (GOV.ARM), J. Mather (GOV.ARM, not on board), J. Creamean (EDU.CSU), K. Pratt (EDU.UM, not on board), G. de Boer (EDU.CU), K. Dethloff (DE.AWI, not on board), E. Hunke (GOV.AWI), W. Maslowski (EDU.NPS, not on board), A. McComiskey (GOV.ARM, not on board), O. Persson (EDU.CU), D. Randall (EDU.CSU, not on board), M. Tjernstrom (SE.SU, not on board), D. Turner (GOV.NOAA, not on board), J. Verlinde (EDU.UP, not on board), V. Castro (GOV.ARM), J. Viegas (GOV.ARM), S. Griffiths (GOV.ARM), B. Cunha (GOV.ARM), W. King (GOV.ARM), P. Ortega (GOV.ARM), T. Silva (GOV.ARM), J. Bilberry (GOV.ARM), A. Allen (GOV.ARM), P. Argay (GOV.ARM), D. Greenamyer (GOV.ARM), J. Ellis (GOV.ARM), J. Uin (GOV.ARM), M. Krassovski (GOV.ARM), M. Boyer (GOV.ARM)

Objectives

To understand the changing Arctic sea ice at a fundamental level requires a detailed accounting of energy flow through the sea ice system. While it is clear that atmospheric energy fluxes are critically important for the sea ice energy budget, many processes controlling these fluxes, and their interactions, are poorly understood and represented in numerical models. This project aims to observe specific processes that control the flow of energy through the Arctic atmospheric system and thereby to address pressing science questions under four broad topics.

(a) Surface Energy Budget: What is the annual evolution of the surface energy budget over young sea ice? What are the key process interactions determining the surface energy budget?

(b) Clouds and Precipitation: What factors determine Arctic cloud phase partitioning? What role do clouds and precipitation play in determining low-level atmospheric structure? How does surface inhomogeneity influence the spatial structure of cloud-precipitation systems?

(c) Aerosols: How do aerosol physical, chemical, and optical properties over sea ice vary seasonally? What sources and transport patterns are responsible for variability in Arctic aerosol? What are the radiative and cloud-nucleating properties of Arctic aerosol?

(d) Boundary Layer Structure: What are the properties and effects of stably stratified turbulence in the Arctic boundary layer? What are the effects of a thinned ice cover on boundary layer stability and heat fluxes? How do surface- and cloud-driven dynamics impact the boundary layer structure?

Work at sea

To provide the diverse and detailed atmospheric measurements needed to address the primary scientific objectives of the project, the US Department of Energy's Atmospheric Radiation Measurement (ARM) Program (www.arm.gov) will deploy its second ARM Mobile Facility (AMF-2) onboard and nearby *Polarstern* during MOSAiC. This extensive suite of instruments will be operated in a collection of six laboratory sea-containers that will be installed on the bow of *Polarstern*, as well as adjacent to the Met City installation on the sea ice. The AMF-2 facility can be described via five instrument collections:

(a) Meteorology and Wind: Beam-steerable radar wind profiler (BSRWP), meteorological stations, contributions to the radiosonde programme (led by AWI).

(b) Clouds: two- and three-channel microwave radiometers (MWR), vertically-pointing Ka- and W-band cloud radars (KAZR, WACR), a scanning Ka-band cloud radar (Ka-SACR), a ceilometer, a high spectral resolution lidar (HSRL), a micropulse lidar (MPL), and a total sky imager (TSI).

(c) Precipitation: A scanning X-band radar (X-SACR), an optical rain gauge (ORG), a present weather detector (PWD), a weighing bucket gauge, and a parsivel disdrometer.

(d) Radiation: A full set up upward and downward looking broadband longwave and shortwave radiometers (SKYRAD, GNDRAD), multiple redundant sets of upward looking radiometers (ShipRAD), infrared thermometer (IRT), multi-filter rotating shadowband radiometer (MFRSR), and up- and down-looking spectra infrared interferometer (AERI), sun photometer.

(e) Aerosols: Nephelometer, Particle Soot Absorption Photometer (PSAP), condensation particle counter (CPC), ultrafine condensation particle counter (UCPC), Scanning Mobility Particle Sizer (SMPS), Ultra High Sensitivity Aerosol Spectrometer (UHSAS), Hygroscopic Tandem Differential Mobility Analyzer (HTDMA), cloud condensation nucleus counter (CCN), Aerosol Chemical Speciation Monitor (ACSM), single-particle soot photometer (SP2), O3, CO, and N2O concentrations.

In addition to these AMF-2 instruments, ARM has agreed via a proposal process to host and operate instrumentation for two collaborating scientists, Jessie Creamean and Kerri Pratt. These guest instruments include ice nucleus filters, drum samplers, and impactors, and will directly augment the core ARM facilities.

The ARM facility will be supported by 3 on-site technicians for the duration of MOSAiC, with a number of additional deployment personnel at the beginning of the project. Participation of Shupe, Creamean, and Pratt is supported by the DOE Atmospheric System Research Program.

Preliminary (expected) results

Primary results from the AMF-2 deployment at MOSAiC will be an extensive collection of high-quality data sets from the AMF-2 instrumentation that are as continuous as possible for the full year. These data sets will be quality assured by a large team of instrument mentors and facility managers. Based on these data sets, a suite of value-added products will also be derived to provide information on geophysical parameters related to the atmospheric state, clouds, aerosols, vertical atmospheric structure, and others. These data sets are intended to support a great deal of process-based research in support of advancing knowledge, assessing models, and developing improved models for representing climate processes.

Data management

All data produced by the ARM Program during MOSAiC will be automatically ingested and stored on ARM’s onboard “site data system,” which performs many operational tasks involved with data management, initial data ingesting and formatting, data quality checks, and the production of quicklook plots of the data. Quicklooks and the raw ingested data will be available to other scientists onboard *Polarstern*. To the extent possible, quicklooks and relevant summary data will also be transferred in near real time to the ARM data management facility in the U.S. and served for public access. After each MOSAiC leg, the full set of collected data will be physically transported to the ARM data management facility and promptly ingested into a full set of data files that will then be publicly available via that ARM Data Archive (www.archive.arm.gov). Raw data will be available within a couple of weeks of its arrival at the data management facility. Based on this raw data, a suite of value-added products will also be developed in the following months, with these products also being served at the ARM Archive. Appropriate meta-data sharing and cross-linking will occur via the MOSAiC Central Storage and with PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) according to the protocol agreed upon between these two archives.

All data are handled, documented, archived and published following the MOSAiC data policy. Exceptions will to be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

References

NONE.

3.4 Wind and turbulence structure in the Arctic boundary layer

A. Preußer (DE.UNITRIER), G. Heinemann (DE.UNITRIER, not on board)

Objectives

In order to understand the New Arctic and its future development, improved numerical models and new verification data are needed particularly for the atmospheric boundary layer (ABL). The project will contribute to the MOSAiC measurement network with a scanning Doppler lidar to observe aerosol backscatter and wind. The measurements will provide wind profiles with high spatial and temporal resolutions. In addition, Doppler wind lidar measurements allow for the determination of the turbulence structure of the ABL. The possibilities of the lidar will be expanded through the synergy with other MOSAiC groups. Particularly, it is planned to have a combination with a second scanning wind lidar (group of Univ. Leeds) which will enable to establish ‘virtual towers’ for wind profiles at different positions, measure TKE profiles as well as the horizontal wind field and its turbulence structure. The project will study the Arctic ABL structure, its turbulent dynamics and the controlling physical processes over a full annual cycle. A high-resolution data set of wind and turbulence profiles for the verification of numerical models in the Arctic will be generated.

Work at sea

Measurements will be performed with our “Halo-Photonics Streamline“ (HPS) scanning wind lidar (Fig. 3.1), which operates at a wavelength of 1.5 µm and is eye-safe. The lidar can operate with a maximum range of 10 km. Previous campaigns have shown that the range is restricted by the low aerosol concentration in the Arctic and Antarctic, which can partly be compensated by increasing the averaging interval and adjusting the beam focus in order to optimize the signal-to-noise ratio (SNR), as recommended by Hirsikko et al. (2014). The used lidar is a programmable scanner, which enables vertical scans in all hemispheric directions.

Fig. 3.1: The HPS lidar on board Polarstern (P-Deck). Photo by Andreas Preußer (2017)

The main scan patterns are the vertical azimuth display (VAD), the range-height indicator (RHI), horizontal scans with fixed azimuth or only in vertical direction (horizontal/vertical STARE) and continuous horizontal scans (plane position indicator, PPI). Since the measured wind signal of a single beam is only the radial wind component (line-of-sight (LOS) wind), at least two different scan angles with respect to the wind vector are needed. The VAD is used for the determination of wind profiles above the lidar with eight scans with a zenith angle of 15° and 45° azimuth steps. The horizontal STARE mode is used at two or three azimuth angles, which are adjusted to the heading of the ship and the wind direction. The RHI mode is generally applied together with the STARE mode and at the same azimuth angles. RHI scans are performed with different elevation angles up to 40°. This allows for measurements of cross-sections, but also for vertical profiles of horizontal wind variances (TKE estimation, Banta et al. 2006). Vertical STARE data will be used to compute the vertical wind variance profile (see Päschke et al., 2015).

In order to correct the lidar data with respect to ship motions and the ship's orientation, data of the ship's navigation system are used (Zentek et al., 2018). In addition, a high-frequency Attitude Heading Reference System can optionally be mounted at the lidar. The lidar has an integrated GPS, which will be used for frequent time synchronization of the lidar processing computer.

The lidar will be operated on all legs. On PS122/1 and PS122/3, we will combine our wind lidar with the HPS wind lidar of the group of Univ. Leeds (Achert et al., 2015; Brooks et al., 2017). Through this combination of two scanning wind lidars we can realize the virtual towers for wind profiles at different positions, derive TKE profiles and can measure the 2D wind field and turbulence structure. This information is of extreme value for the evaluation of numerical models. On the other legs, no dedicated lidar operator of Trier or Leeds will be on board *Polarstern*, and a basic lidar measurement programme is planned to be continued with supervision of other scientists of the ATMOS team.

Preliminary (expected) results

The measurements during the *Polarstern* cruise shall yield an extensive data set of continuous and high-resolution vertical profiles of wind and aerosol backscatter. The data analysis will comprise the climatology and process studies of low-level jets as well as the ABL turbulence structure. We will use the data for the verification of simulations using a high-resolution regional climate model and for process studies, besides potential further usage by other scientists within the MOSAiC consortium.

Data management

All lidar data obtained during the cruise will be stored on a laptop, on USB disks and in the MOSAiC data-management system (i.e., MOSAiC Central Storage – "MCS"). The processed data will be stored in the PANGAEA data base (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).

All data are handled, documented, archived and published following the MOSAiC data policy.

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3.5 ALEXIA - Analysis linking Arctic methane, carbon release, heat fluxes and sea ice from local to sub-regional scales by airborne measurements

F. Pätzold (DE.TUB), A. Lampert (DE.TUB, not on board), S. Nowak (DE.TUB, not on board), L. Bretschneider (DE.TUB, not on board), E. Damm (DE.AWI), A. Rinke (DE.AWI), T. Sachs (DE.GFZ), H. Chen (NL.RUG, not on board), S. van Heuven (NL.RUG, not on board)

Objectives

In the Arctic, climate change is progressing at a much faster pace than at lower latitudes (Solomon et al., 2007). The phenomenon is referred to as “Arctic Amplification”, addressing the fact that in the last 25 years, the near surface temperatures have increased at a much higher rate than the overall global warming. This is attributed to different complex feedback mechanisms.

To study these feedback mechanisms, a comprehensive airborne data set will be collected with the helicopter-towed sonde Helipod. Besides instrumentation for meteorological parameters, radiation and greenhouse gases, sensors for characterizing aerosol properties, surface roughness and ozone are implemented.

On the one hand the focus of the observations will be to quantify the variability of parameters on a scale of up to 100 km in order to constrain the representativeness of parameters recorded continuously from the Central Observatory at the *Polarstern* and the Distributed Networks.

On the other hand, detailed studies of local effects, like the opening of leads in sea ice and the impact on heat fluxes, trace gases and generally interaction of sea ice/water and atmosphere, are possible. Flight patterns suggested by e.g. Tetzlaff et al. (2015) serve as base for gathering data, which can be included in numerical simulations.

Of particular importance is a deeper understanding of the methane cycle. The sea ice covered ocean appears to act as a source of atmospheric methane yet unaccounted for. Methane super-saturation detected in the vicinity of marginal ice zones, under multiyear sea ice and in polynyas focuses the view especially on the pathways of methane discharge from sea ice (Damm et al., 2007; Kiditis et al., 2010; Zhou et al., 2014). Processes like methane production and consumption occurring in sea water and sea ice can be traced by the $\delta^{13}C$ values (Damm et al., 2005; Mau et al., 2013). In addition, the fate of submarine vent derived methane in the modern carbon cycle can be followed (Damm et al., 2003; Damm et al., 2005; Keir et al., 2009). Discovering the pathways of *in-situ* produced or submarine released methane in the seasonal ice-covered ocean reveals potential sources for atmospheric methane (Jud and Hovland, 1988). Eventually, by comparison of the methane concentration and the carbon isotopic ratio in air samples with the regional background the incremental input of methane in an air parcel and the source $\delta^{13}C$ signature can be determined (Fischer et al., 2011). Using this technique, the extent of methane exchange between the ocean and sea ice with the atmosphere can investigated. A research focus is the pivotal issue of the extent of methane exchange that takes place into and out of the ice as well as processes within the ice.

Fig. 3.2: The Helipod and its instrumentation

Helipod operations for linking atmosphere – sea ice – biogeochemistry from Polarstern on multiple scales

The Helipod (Bange and Roth, 1999; van den Kroonenberg and Bange, 2007; Lampert et al., 2018) is a measurement system equipped with meteorological sensors, greenhouse gas instruments, and systems for observing surface properties (Fig. 3.2). It will be operated with a helicopter based on the *Polarstern*. Helipod is an autonomous streamline fuselage without own propulsion, therefore the sensors are subject to a very low level of vibrations only, which improves the performance of some sensors dramatically (Lampert et al., 2018). Helipod has an own power supply, and data are transferred by wireless connection from the central onboard computer to the laptop computer of the operator in the helicopter.

Helipod provides high resolution *in-situ* data of meteorological parameters, energy fluxes from the surface into the atmosphere, concentration profiles and fluxes of the greenhouse gases carbon dioxide and methane. For further linking the observations to other research fields, the Helipod is equipped with sensors to measure surface temperature as an indicator of sea ice concentration, broadband upwelling and downwelling shortwave irradiance as an indicator of cloudiness and albedo, aerosol properties, ozone concentration and surface roughness, and it provides the capability of taking air samples for detailed analysis of the methane isotopic signature in the laboratory, to derive the origin of the enhanced methane concentration in the atmosphere (biogenic/ fossil origin).

The overall aim is to constrain the methane cycle at high latitudes, identify the origin of the enhanced atmospheric methane concentration by isotopic analyses and reconstructing pathways of methane into the high-latitude atmosphere (turbulent fluxes vertically upwards from the surface or long-range advection), and investigate factors influencing the source strength and distribution.

Work at sea

The Helipod of TU Braunschweig (van den Kroonenberg and Bange, 2007; Lampert et al., 2018) is operated directly from *Polarstern* with the onboard helicopters. Helipod will link the Central Observatory and different ice stations distributed within some km from the ship, and expand the observations to a range of 100 km, so that the spatial variability of the other observations can be determined on climatically relevant scales. Helipod has the aim to investigate the origin and pathway of the enhanced Arctic methane concentration, and deliver data of high relevance for satellite validation. A coupling of sea ice/sea water field work with simultaneous airborne measurements is planned to determine the pathways from ocean water and sea ice into the atmosphere. The tracing of methane will be carried out by its $\delta^{13}C$ signature measured in high precision in air, sea water and sea ice samples.

Helipod will be operated around once per week on PS122/3 and PS122/4 during daylight. A measurement flight takes about 2 h. Trajectories and air-sample distribution will be chosen depending on the current situation. Long distance transects, vertical profiles and locally stacked legs can be combined to observe potential local sources as well as fluxes over homogenous terrain.

The methane $\delta^{13}C$ signature and concentration of the air samples will be analyzed with a PICARRO 2132 on board.

Preliminary (expected) results

A comprehensive data set of meteorological parameters, greenhouse gas concentrations, radiation, surface properties and aerosol properties will be gathered along transects and in the vicinity of *Polarstern* on smaller scales.

The methane $\delta^{13}C$ signature and concentration of the air samples will be analyzed. The data set will be analyzed with different foci of investigation as described above.

Data management

Data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).
All data are handled, documented, archived and published following the MOSAiC data policy.

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3.6 UAV measurements

T. Sachs (DE.GFZ, not on board), M. Zöllner (DE.GFZ)

Objectives

In continuing the PS122/3 - PS122/5 UAS group's measurements during PS122/6, we aim to contribute data to the three central UAS themes, i.e. investigating

- the vertical structure of the atmospheric boundary layer via regular profiling of the lower atmosphere and turbulence measurements (3D wind, temperature, humidity)
- the spatial variability and gradients of turbulent fluxes of heat, momentum, CO_2 and (potentially) CH_4 over various surfaces (e.g. ice, decaying ice, leads)
- difficult to sample areas, e.g. over leads or extremely thin ice

Airborne observations will be carried out using a vertical take-off and landing (VTOL) fixed-wing UAV (Wingcopter Heavylift).

Work at sea

Flight patterns will depend on meteorological conditions and on the sea ice situation. The main focus is on vertical profiling of the ABL and the horizontal variability of atmospheric parameters and turbulent fluxes at constant flight altitudes. Opportunistic measurements of lead energy budgets will be made depending on lead development.

Actual flight levels will depend on the ABL depth, which will be estimated prior to the flights from available soundings or balloon profiles.

Preliminary (expected) results

We expect to extend the data collection of the PS122/3 - PS122/5 UAV groups into PS122/6 and thereby contribute to unique datasets on the vertical structure of the ABL, turbulence, and the surface and potentially lead energy budgets.

Data management

All atmospheric raw data collected with the GFZ Wingcopter will be stored in the onboard MCS as quickly as possible after each flight. Final data will be delivered to the PANGAEA database (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) after post-cruise calibration and processing.

All data are handled, documented, archived and published following the MOSAiC data policy.

References

NONE

3.7 Atmospheric surface fluxes for understanding sea-ice thermodynamics and dynamics

M. Shupe (EDU.CU), T. Ayers (GOV.NOAA, not on board), D. Costa (EDU.CU), C. Cox (EDU.CU), C. Fairall (EDU.NOAA, not on board), D. Gottas (EDU.NOAA, not on board), J. Leach (EDU.NOAA, not on board), S. Morris (EDU.CU, not on board), J. Osborn (EDU.CU), O. Persson (EDU.CU), S. Pezoa (GOV.NOAA, not on board), T. Uttal (GOV.NOAA), I. Brooks (UK.UNI-LEEDS), J. Hutchings (EDU.ORSU), D. Perovich (EDU.DARTMOUTH), T. Stanton (EDU.NPS, not on board)

Objectives

This project aims to examine in detail the interplay of sea-ice thermodynamic and dynamic processes and how these control the state of the ice over a full year. In support of this overall goal, project objectives include:

(a) Build comprehensive sea ice energy, upper ocean heat, and sea-ice momentum budgets; examine how these co-vary in space and time over all seasons of the year; and develop temporally-evolving process relationships among multiple key parameters.

(b) Use detailed field observations and a coupled regional model to examine how energy transfer processes (thermodynamics) are influenced by sea-ice deformation (dynamics) on sub-seasonal to seasonal time scales.

(c) Assess sea-ice predictability related to dynamic and thermodynamic process relationships, using a full year of quasi-operational, 10-day sea-ice forecasts.

This project includes activities falling within the MOSAiC ATMOS, OCEAN, and ICE teams. The ATMOS components will be primarily described here, with reference to the other components for context. Further information on OCEAN and ICE components is available in the sections describing the work from those teams at MOSAiC.

This project is funded by the US National Science Foundation and the US National Oceanic and Atmospheric Administration.

Work at sea

Heat and momentum fluxes at the atmosphere-ice interface will be measured at Met City on the ice near the *Polarstern* and at three sites across the MOSAiC Distributed Network. At Met City, approximately 600 m from *Polarstern* in the MOSAiC ice camp, will be an 11 m meteorological tower adjacent to a 30 m meteorological mast. The 30 m mast is operated in collaboration with Ian Brooks (Univ. of Leeds, UK). These installations will be the furthest permanent installations from *Polarstern* to minimize turbulent interference from other structures. They will include measurements of pressure (2

m), temperature and relative humidity (2, 6, 11, 30 m), high-frequency three-dimensional winds (2, 6, 11, 30 m), high frequency moisture and carbon dioxide concentrations (2 or 6 m), surface height (2 m), surface infrared temperature (2 m), and surface heat flux (0 m). All of these instruments will have local data logging with real-time back-up of data on *Polarstern* via the network connection. Collectively this set of instruments will be used to characterize near surface atmospheric structure and surface turbulent heat fluxes. When combined with measurements from a radiation suite (provided by DOE ARM and the Finnish Meteorological Institute), all terms of the atmospheric surface heat flux will be derived. At the three L-sites within the MOSAiC Distributed Network (~15 km distant from *Polarstern* at the beginning), the project will install Atmospheric Surface Flux Stations (ASFS) that include measurements at 0-3m height of pressure, temperature, relative humidity, high-frequency three-dimensional winds, high-frequency water vapor and carbon dioxide concentrations, surface height (snow depth), surface infrared temperature, surface heat flux, and up- and down-welling longwave and shortwave radiation. These remote facilities will log all data locally and transfer a complete set of data back to *Polarstern* via radio modems or an abbreviated summary set of data to *Polarstern* via satellite communications. Adjacent to these atmospheric surface flux measurements at each of the four locations will be an ice mass balance buoy (D. Perovich) for measuring ice thickness and thermodynamic structure, and an Autonomous Ocean Flux Buoy (T. Stanton) for measuring ocean fluxes of heat, momentum, and salt. Jointly these measurements allow for a full documentation of the thermodynamic state of the sea ice. Additionally, an array of GPS position buoys (J. Hutchings) will be installed across the full MOSAiC Distributed Network to provide detailed information on ice dynamics.

The Met City installations will be visited and maintained on a daily basis by two onboard scientists / operators. These operators will also visit each of the ASFS systems approximately once per month via helicopter to maintain the systems and retrieve a copy of all data.

Preliminary (expected) results

Measurements made as part of this project will provide a full year of high-quality estimates of atmospheric surface heat and momentum fluxes at four locations across the MOSAiC domain, as well as detailed lower atmospheric structure at the MOSAiC ice camp. These fluxes will be combined with project partner measurements of ocean heat fluxes, sea ice thermodynamic state and thickness, and regional-scale sea-ice movement and deformation. These products will be used to assess quasi-operational 10-day model forecasts from the regional Coupled Arctic Forecast System (CAFS). Additionally, the products will be widely useful for research examining the surface energy budget, atmospheric stability, turbulent exchange of various parameters, and other topics.

Data management

Data produced at the Met City installation will be archived locally in Met City and duplicated in the flux laboratory container onboard *Polarstern*. Data produced at the remote ASFS sites will be archived locally on the systems; some sub-set of this data will be transferred to *Polarstern* via a combination of radio modems, satellite modems, and site visits. All data will be redundantly archived on the server in the flux laboratory container onboard *Polarstern*. Additionally, a copy of all data will be uploaded on the MOSAiC Central Storage onboard *Polarstern*. Long term archival of quality-controlled data will be done on PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) and/or on the Arctic Data Center archive, according to the protocol agreed upon between these two archives.

All data are handled, documented, archived and published following the MOSAiC data policy. Exceptions will to be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

References

NONE

3.8 MOSAiC Boundary Layer

I. Brooks (UK.UNI-LEEDS), R. Neely (UK.UNI-LEEDS, not on board), B. Brooks (UK.NCAS, not on board)

Objectives

The Arctic atmospheric boundary layer is poorly represented within numerical models, but plays a critical role in governing the interactions between the atmosphere and the surface. The boundary layer has a major impact on cloud properties, which in turn are the strongest factor influencing the surface energy budget, and also the largest source of uncertainty in the energy budget within models. Our overarching goal is to develop a new understanding of the physical processes governing atmospheric boundary layer structure, turbulent mixing, and the interactions with both the surface and cloud in the central Arctic.

Specific objectives are to:

1. **Characterize the turbulent dynamics of the Arctic atmospheric boundary layer and the physical processes controlling it over a full annual cycle.** BL mixing directly affects the surface heat flux and both influences cloud properties and is influenced by in-cloud processes, and thus impacts the radiative fluxes and surface energy budget, contributing to ice formation/melt.
2. **Determine the interactions of Arctic boundary layer structure with the surface turbulent fluxes of momentum and heat**. Surface fluxes are a controlling influence on lower BL structure. Elevated sources of turbulence, e.g. wind speed jets and radiative cooling at cloud top, dominate the control of upper BL structure and can impact surface fluxes where surface forcing of turbulence is weak, and thus the surface energy budget and ice evolution.
3. **Identify and describe the significant processes controlling coupling/decoupling of BL cloud to the surface.** Decoupling isolates BL cloud from surface sources of moisture and aerosol; this may affect cloud properties and thus the surface radiation budget.

This project is funded by the UK Natural Environment Research Council.

Work at sea

We will make detailed remote-sensing measurements of the mean and turbulent dynamics of the atmospheric boundary layer throughout the full year of MOSAiC. Our instrumentation suite consists of:

01) A Galion wind-profiling lidar – continuous profiles of wind speed and direction at order 10-m by 1-minute resolution, up to a maximum altitude of ~4 km.

02) Halo Photonics Streamline boundary layer research lidar – retrievals of turbulent dissipation rate, velocity variance and turbulent kinetic energy (TKE) profiles, etc. Coordination of measurements with an identical instrument from project partner Heinemann will enable enhanced measurements including ‘virtual tower’ profiles of momentum flux (Section 3.4)

03) Scintec M-FAS phased array sodar – continuous profiles of wind speed and direction from 30m to ~500 m at 10-m by 10-minute resolution, and boundary layer mixing structure at 10-m by 5-minute resolution.

The Galion lidar and Scintex sodar will both make continuous measurements of the vertical profile of wind speed and direction. The local wind profile is a strong control on surface fluxes (O2), the vertical turbulent structure of the boundary layer as a whole (O1), and entrainment at cloud top, all of which depend critically on shear forcing – the vertical gradient in the wind. The near-surface wind shear is closely coupled to the surface momentum flux and maintains a mechanically well-mixed surface layer against thermodynamic stratification. Higher in the BL, the combination of wind shear and thermodynamic structure control turbulent mixing and coupling/decoupling of the surface and BL clouds, while shear across the inversion at BL top can enhance entrainment mixing against the stability of the inversion. In stable conditions, turbulence is driven entirely by wind shear, and may be sporadic, requiring profile measurements at high time-resolution to isolate individual mixing events.

Turbulence properties will be derived via several different techniques. The acoustic backscatter from the sodar allows a temperature structure function to be calculated, this provides information on the vertical mixing state of the lower atmosphere. The vertical velocity variance from the sodar provides direct information on vertical mixing. The two HALO lidars will be used to make synchronized scans of the same volume of air. Over a period of 10-15 minutes, this will allow information on velocity covariances to be derived. Depending on the geometry of the viewing angles, in some cases a direct estimate of the momentum flux to the surface can be estimated. Each lidar alone can also be used to derive some information on the vertical profile of turbulence through time-averaging of range-height indicator scans (scanning through a range of elevation angles at constant azimuth).

During the passage of frontal systems, horizontal scans of the Halo lidars through a wide range of azimuth angles will provide information on the divergence of the local wind field – and important control on ice deformation.

Preliminary (expected) results

Detailed profiles of wind speed and direction at high time and vertical resolution will be produced for the full year. Information on the turbulence structure of the boundary layer will be derived continuously from the sodar, and on a discrete (non-continuous) basis from the Halo lidars, dependent upon conditions.

Data management

Raw data is stored on a dedicated RAID system on board *Polarstern*, and transferred to shore by USB drive at the end of each leg. Processed data will be archived at NERC's data centre (CEDA) or PANGEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)). All data are further handled, documented, archived and published following the MOSAiC data policy. Exceptions will to be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

References

NONE

3.9 Surface exchange of climate-active trace gases in a sea ice environment during MOSAiC

B. Blomquist (EDU.CU), S. Archer (ORG.BIGELOW), D. Helmig (EDU.CU, not on board), L. Ganzeveld (NL.WUR), C. Fairall (EDU.NOAA, not on board), L. Bariteau (EDU.CU), D. Howard (EDU.CU), J. Hueber (EDU.CU), H. Angot (EDU.CU), K. Posman (ORG.BIGELOW), S. Barten (NL.WUR, not on board), H.-W. Jacobi (FR.Univ-grenoble-alpes), W. Sturges (UK.UEA, not on board)

Objectives

Changing sea ice cover has the potential to affect global climate patterns and biogeochemical processes, including air-sea exchange of climate-active trace gases, with uncertain feedbacks to global warming in general. Model representations of the important processes responsible for and responding to these changes are generally deficient. Development of physical gas transfer parameterizations and of biogeochemical sea ice models incorporating trace gas dynamics are limited by a paucity of direct observations.

This project will focus on surface flux measurements of four climate-active trace gases: carbon dioxide, methane, dimethylsulfide, and ozone (CO_2, CH_4, DMS, O_3). Continuous eddy correlation flux measurements will be obtained from a ship-mounted meteorological tower and from a 12 m surface flux tower located at the ice camp ~0.5 km from the ship. Complementary dynamic-chamber flux measurements will be conducted on a weekly basis to constrain gas transfer over a variety of ice and snow surfaces and link these fluxes to potential sources and sinks in sea ice throughout the freeze-melt cycle. Fluxes will be interpreted with respect to the chemical, biological, and physical characteristics of seawater and sea ice provided by collaborating MOSAiC teams.

The atmospheric modeling component of this study uses a 1-D chemistry-climate modeling system (Ganzeveld et al. 2002; Seok et al., 2013) to link measurement and process-level modeling activities to regional scales. A physical gas transfer model appropriate for the sea ice environment will be developed and added to the current 1-D system. This model will be used to investigate the role of sub-grid processes at larger scales with the modelling system running in a so-called Lagrangian mode, transporting the system along wind trajectories over a distance greater than grid-box scale (~100-300 km) to resolve effects of transitions in open ocean–sea ice cover on surface fluxes, where open leads typically yield enhanced heat flux and vertical mixing. Finally, the 3-D global climate-chemistry model EMAC will be updated to include gas transfer in the seasonal ice zone, facilitating a broader assessment of the sensitivity of regional and global trace gas budgets to Arctic climate change and to estimate potential feedbacks.

This project is funded by the US National Science Foundation and National Oceanic and Atmospheric Administration.

Work at sea

A 20-ft. laboratory container will be installed in the ship's forward hold with gas sampling lines and data cables extending to the top of the ship's bow mast for gas flux and bulk meteorological measurements. Gas analyzers include an Atmospheric Pressure Ionization Mass Spectrometer (APIMS) for DMS flux (Blomquist et al., 2010), a cavity ring-down spectrometer for CO_2 and CH_4 (CRDS, Picarro G2311-f, Blomquist et al. 2014), and a Fast Response Chemiluminescence Instrument for ozone flux (FRCI, Bariteau et al., 2010). Gas analyzers will be integrated with *in-situ* data from a Metek u-Sonic3 anemometer, a LI-COR 7500DS H_2O/CO_2 analyzer (for water vapor flux), and bulk temperature and humidity sensors.

Additional trace gas species sampled from the ship tower will include nitrogen oxides (NO_x/NO_y) using a chemiluminescence analyzer, volatile organic compounds with an automated Agilent GC-mass spectrometer system, and elemental mercury measurements with a Tekran analyzer. These measurements will provide a more complete understanding of background atmospheric chemistry conditions over the duration of the project and are essential for the atmospheric modeling studies.

Instrumentation at the ice camp flux tower site will include a Picarro G2311-f for CO_2/CH_4 fluxes, an FRCI for ozone flux, and a slow ozone analyzer for surface deposition studies in the vicinity of the tower. Supporting fast wind measurements will be conducted by a collaborating group.

The dynamic-chambers are portable systems intended for short-duration surface flux measurements at multiple locations with minimal disruption of the snow or ice surface. Chamber systems for CO_2/CH_4, DMS and ozone will be deployed independently. Surveys will be conducted within the footprint of the EC-flux measurements and in the vicinity of sea ice sampling locations. Because sea ice is heterogeneous, sampling at multiple locations will be used to develop a statistical representation of trace gas surface fluxes over a variety of ice and snow conditions. We will conduct these surveys on a weekly basis throughout the project, conditions permitting.

Preliminary (expected) results

The project will provide a time series of direct gas exchange measurements for CO_2, CH_4, DMS and O_3 over the annual sea ice cycle. Combined with physical, chemical and biological characterization of the sea ice environment over the same period, these observations afford insight into process-level mechanisms controlling gas transfer and validate modelling approaches for physical gas transfer algorithms and sea-ice biogeochemical models. Coupling improved process-level algorithms into 1D and 3D chemistry-climate models permits an assessment of regional and global impacts of air-sea gas transfer in the Arctic sea ice environment.

Data management

Raw and field-processed data will be copied to the MOSAiC Central Storage aboard *Polarstern*. Raw and processed/derived results will be archived in PANGEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) and/or the NSF Arctic Data Center, according to the protocol agreed upon between these two archives.

All data are further handled, documented, archived and published following the MOSAiC data policy.Exceptions will to be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

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Seok, B, Helmig D, Ganzeveld L, Williams MW, Vogel CS (2013) Dynamics of nitrogen oxides and ozone above and within a mixed hardwood forest in northern Michigan, Atmospheric Chemistry and Physics, 13, 7301-7320, doi:10.5194/acp-13-7301-2013.

3.10 Collaborative Aerosol Projects: (a) Formation of secondary nano-sized aerosol particles from atmospheric trace gases and ions in the polar marine environment, and (b) Measurement-Based undeRstanding of polar Aerosols and their Climate Effects (MBRACE)

J. Schmale (CH.PSI), T. Jokinen (FI.UNI-Helsinki), L. Quéléver (FI.UNI-Helsinki), T. Laurila (FI.UNI-Helsinki), Z. Brasseur (FI.UNI-Helsinki, not on board), I. Beck (CH.PSI)

Outline

The overall effect of ice loss and consequent enhanced ice mobility and lead opening to aerosol emissions cannot be estimated with present understanding. The related sources and formation mechanisms of aerosols in the Arctic and polar marine environments are yet to be resolved. To quantify the effect of these to the climate above the Arctic Circle, the whole annual cycle of ice cover evolution must be covered by continuous measurements addressing all relevant interacting components.

Objectives

This project is a collaboration between the Paul Scherrer Institute and the University of Helsinki. The collaborative project focuses on understanding linkages between sea ice dynamics and thermodynamics, surface and ice characteristics, oceanic aerosol precursor concentrations and emissions, atmospheric boundary layer dynamics and cloud formation and how these vary from polar night with no solar radiation to polar summer with 24/7 solar radiation and the start of photochemistry. We focus on improving the process level understanding of local aerosol particle formation (sources of trace gases, oxidizing agents in the polar atmosphere, and links to the ecosystem), as well as developing a comprehensive microphysical and chemical characterization of high Arctic aerosol that will enable an understanding of its transformation in the atmosphere and ability to form cloud condensation and ice nuclei. At the same time, the project will identify periods where the atmosphere exhibits a preindustrial-like aerosol regime as opposed to conditions in which pollution from lower latitudes prevail. Finding the preindustrial aerosol benchmark in the Arctic will further inform anthropogenic radiative forcing contributions through aerosol-cloud interactions, which rely on the preindustrial state of the atmosphere as reference. Tight collaboration with global aerosol and climate modelling groups will be part of the project.

Main questions are: What are the distinctions between pre-industrial Arctic air masses versus those impacted by pollution? What are the roles of different precursors on initial aerosol formation? What is the molecular composition of fresh aerosol particles and how is it affected by precursor emissions? What are the contributions of new particle formation versus long-range transport to CCN concentrations and what vapors are responsible for the growth to CCN sizes? What are the key processes governing the annual cycle of aerosols during different seasons as concerns local sources, long-range transport and scavenging. In which form are iodine and sulphur compounds emitted from the Arctic Ocean and sea ice, and how do the emissions vary with season or ice characteristics? How is precursor production affected by cosmic rays and photochemistry? How does sea ice as a source of aerosol precursors, secondary aerosol and CCN compare to open polar waters? Does marine and ice biological activity provide different sources of precursors? How do cloud radiative properties depend on the CCN concentration?

Work at sea

Our atmospheric measurements will be made from a laboratory container from the Paul Scherrer Institute that will be operated on the bow of *Polarstern*, with some additional measurements made in the adjacent laboratory container from the British Antarctic Survey (M. Frey). All measurements will be made through three inlets (new particle, interstitial, and total) mounted on the top of the container bringing ambient air into the online instrumentation inside the container. Sampling will be continuous with monitoring for local pollution events. The collection of instruments will include: various particle counters, a mobility size spectrometer, aerodynamic particle sizer, neutral cluster and air ion spectrometer, atmospheric pressure interface time-of-flight mass spectrometer, aerosol mass spectrometer, cloud condensation nuclei counter, fluorescent particle counter, trace gas monitors, online gas chromatograph, impinge and filter samplers. One person from the collaborative team will participate in each of MOSAiC's six legs and oversee the collective suite of instruments. Work at sea will primarily entail maintenance and surveillance of online instrumentation to support continuous and proper operation. Daily checks of each instrument will be conducted throughout the MOSAiC campaign.

Preliminary (expected) results

Results will focus on distinguishing local versus long-range aerosol processes for impacting the locally measured aerosol population. These will include unique measurements through different inlets that will serve to distinguish aerosol populations, their properties, and their behavior in terms of cloud activity. The suite will include first time measurements of aerosol precursors and nano-sized aerosol particle number concentrations and size distributions from the Arctic Ocean, including concentrations of sulfuric acid, iodic acid, methane sulfonic acid and oxidized organic compounds (both ions and neutral forms). These will provide a mechanistic understanding of new particle formation and subsequent aerosol and cluster growth for the implementation into large scale models. A conceptual understanding will be developed of differences between aerosol characteristics in ice covered versus open oceanic regions, locally produced versus long-range transported aerosol, and the overall effects of diminishing sea ice on the aerosol system. An understanding will be developed of the marine conditions that promote particle formation, transport, and growth to climatically relevant sizes.

Data management

Data is collected on measurement instrument computers and backed up to several external hard disks. The data will be delivered and uploaded to servers on land after every leg. Some data are automatically processed on board (near real time) and some are saved for post campaign analysis. Data products will be saved and shared publicly after the campaign via PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).

All data are further handled, documented, archived and published following the MOSAiC data policy.

References

NONE

3.11 Sea Salt Aerosol above Arctic Sea Ice – sources, processes and climate impacts (SSAASI-CLIM)

M. Frey (UK.BAS), A. Kirchgässner (UK.BAS), T. Lachlan-Cope (UK.BAS, not on board), X. Yang (UK.BAS, not on board), A. Jones (UK.BAS, not on board), L. Clarke (UK.MMU, not on board)

Objectives

Sea salt aerosol (SSA) influences regional climate directly through scattering of radiation or indirectly via its role as a cloud-forming particle. While it is well known that SSA can be cloud condensation nuclei (CCN) forming cloud droplets, it has been shown only recently that SSA can be also a source of ice nucleating particles (INP) forming ice crystals (DeMott et al., 2016), depending on its chemical composition and surface shape. Aerosol processes and interactions with clouds are very complex (Browse et al., 2014) and Arctic clouds are poorly represented in climate models, which is partly due to a lack of understanding of source and nucleating capability of natural aerosol in the high Arctic. Aerosol models for example do currently not capture aerosol maxima in the Arctic winter/spring observed at high latitudes (e.g. Huang et al., 2017). A recent Antarctic sea ice cruise provided first direct evidence of a source of SSA from salty blowing snow (BSn) above sea ice (Frey et al., 2019), which had been hypothesized previously (Yang et al., 2008): during storms, salty snow gets lofted into the air and then undergoes sublimation to generate SSA. Additional but minor SSA sea ice sources are frost flowers and open leads. Taking into account the blowing snow source of SSA improves model predictions significantly (Yang et al., 2019; Huang et al., 2017). However, the impact on radiation and clouds of SSA from this new sea ice source is not known. And a quantitative understanding of natural aerosol processes and climate interactions is needed to provide a baseline against which to assess anthropogenic pollution reaching the Arctic and evaluate the success of mitigation measures (e.g. AMAP 2015).

This project the SSA source strength is to be determined as well as fate and potential impact on Arctic climate associated with blowing snow above sea ice and other sea ice sources. A particular focus is on quantifying the contribution of ice nucleating particles (INP) from sources related to Arctic snow and sea ice. Participation in the year-long Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) provides the unique opportunity to observe key aerosol processes and properties in the central Arctic Ocean throughout all seasons of the year.

The first objective is to quantify SSA variability above sea ice and relative contributions from local sources (blowing snow, frost flowers and open leads) throughout the year. This will be achieved through (a) *in-situ* measurements of particle size distribution and concentration, covering all relevant sizes ranging from the sub-micron scale to the scale of airborne snow particles at various levels within the atmospheric boundary layer and in the free troposphere using a tethered balloon platform. And (b) through chemically fingerprinting the local snow and sea ice source using major ion ratios and sulfur isotopes, and compare these to the chemical composition of aerosol to constrain its contribution to Arctic SSA.

The second objective is to quantify the contribution of SSA above sea ice to cloud forming particles. This will be achieved through (a) measurement of ice nucleating particles (INP) in the air above the sea ice to evaluate their variability associated with SSA concentrations and events (blowing snow, opening of leads). And (b) through testing for the presence of INP in snow on sea ice, brine, frost flowers and link to ambient INP.

The third objective is to determine the climate sensitivity to SSA from the sea ice source (blowing snow, frost flowers, open leads) in the Arctic through numerical modeling based on existing and new MOSAiC observations. This will be achieved through (a) quantification of the direct radiative effect of SSA and (b) quantification of the indirect radiative effect of SSA via its contributions to INP/CCN and their impact on cloud fraction.

Work at sea

Planned year-round measurements on-board *Polarstern* and on the sea ice include particle size and concentration (sub-micron to snow/cloud particle size), INP concentrations, and a range of particle chemical properties using aerosol filters. Tethered balloon launches will yield information on the fate of particles formed near the sea ice surface as they get lofted to heights where clouds may form. Frequent sampling of snow on sea ice, brine, frost flowers will constrain the local source of SSA.

Preliminary (expected) results

The expected year-round datasets of SSA and INP above sea ice, as well as chemical source signature of snow and sea ice from the Central Arctic Ocean will provide important insights into Arctic sea ice as a particle source. They will lead to improved model parameterisations of the SSA blowing snow source as a function of sea ice properties, as well as a better understanding of the potential impact on Arctic clouds. And finally, SSA is also a potential sea ice proxy measured in polar ice cores (Abram, et al., 2013) and quantifying the SSA sea ice source will constrain reconstructions of past Arctic sea ice conditions (e.g. Rhodes et al., 2017).

Data management

Online measurements will be available during or very soon after completion of the MOSAiC cruise in 2020, whereas data from the off-line chemical analysis of aerosol filter, snow and ice samples will become available after completion of lab analysis in the UK by mid 2021. All SSAASI-CLIM data will be made available within the MOSAiC data management framework and will eventually be archived at the British Polar Data Centre and/or PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de))., according to the protocol agreed upon between these two archives. All data are further handled, documented, archived and published following the MOSAiC data policy. Exceptions will be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

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3.12 Observing spatial and temporal variability in atmospheric and surface conditions using unmanned aircraft

G. de Boer (EDU.CU), J. Cassano (EDU.CU) D. Lawrence (EDU.CU, not on board), B. Argrow (EDU.CU, not on board), J. Hamilton (EDU.CU), G. Jozef (EDU.CU), R. Calmer (EDU.CU), D. Weibel (EDU.CU), S. Borenstein (EDU.CU, not on board), S. Morris (EDU.CU, not on board)

Objectives

Recent decades have seen persistent decreases in the extent and thickness of Arctic sea ice (Maslanik et al., 2011; Comiso et al., 2008; Rothrock et al., 1999). This decline has significant consequences in terms of climate (Serreze et al., 2007; Screen and Simmonds, 2010), weather (Vihma, 2014; Francis et al., 2009) and commerce (Smith and Stephenson, 2013; Ho, 2010). Development of modeling tools has helped to project this reduction in sea ice for some time, including projections of a seasonally ice-free Arctic before the end of this century (Jahn et al., 2016), though these models have struggled to accurately capture the rate of decline (Stroeve et al., 2012; Stroeve et al., 2007). While the exact reasons for these discrepancies are not entirely clear, the general transfer of energy between the Earth's surface and the overlying atmosphere, particularly at high latitudes, remain an area of substantial uncertainty in our understanding of the global climate system. The thermodynamic structure of the lower atmosphere plays a central role in regulating processes driving this energy transfer, including cloud structure and radiative influence, and turbulent energy exchange. Significant insight can be gained by measurements focused on the structure of the lower atmosphere, its spatial variability, the intensity of turbulent energy fluxes, and the influence on surface features on this structure, over the central Arctic Ocean ice pack. To provide such measurements, small unmanned aircraft system (sUAS) operations are proposed as part of the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC). In conjunction with other MOSAiC datasets, these measurements will provide revolutionary perspectives on lower atmospheric state and its influence on the surface energy budget.

The proposed measurements will offer an unprecedented look at the three-dimensional structure of the lower atmosphere over the central Arctic Ocean and the spatial variability of surface properties over a variety of seasons. The sUAS will provide: 1) detailed information on the vertical structure of lower atmospheric thermodynamic (pressure, temperature, humidity) and dynamic (wind) structure; 2) information on the spatial variability of these quantities, turbulent fluxes of heat and moisture between the surface and atmosphere and surface properties such as albedo, surface temperature and ice fraction; 3) information on the influence of sea ice leads on the overlying atmosphere and underlying ocean and 4) measurements of surface albedo and surface properties like melt pond fraction and sea ice fraction over the area around *Polarstern*. In total, six months of comprehensive measurements are proposed, from mid-February to mid-August, which will allow for the sampling of a wide range of conditions while simultaneously providing a logistically-favorable environment with abundant daylight and a solid ice surface from which to operate unmanned aircraft. After the measurement campaign has been completed, a series of hypotheses will be evaluated using our measurements in conjunction with those from other MOSAiC projects together with a variety of modeling tools. Additionally, evaluation of the performance of regional models and reanalyzes will be completed using our measurements, and we believe that the proposed measurements will provide a critical ancillary dataset for a variety of studies undertaken as part of MOSAiC, as the detailed boundary layer and surface structure will help to inform studies on a variety of topics.

The proposed field work along with subsequent data analysis and modeling work is geared towards addressing three primary hypotheses:

H1) There is sub-grid scale variability in the coupled system that is not represented by today's modeling tools, resulting in errors in the simulated surface energy budget

H2) Leads in sea ice contribute significant amounts of energy to the atmosphere and such transfer is under-represented by models, resulting in errors in simulated boundary layer structure and clouds

H3) Models lack the vertical resolution necessary to simulate the complex structure of the central Arctic boundary layer and its evolution, resulting in errors in simulated energy budgets and cloud formation

This project is funded by the US National Science Foundation and National Oceanic and Atmospheric Administration.

Work at sea

During our time at sea, we will deploy three different sUAS, the DataHawk2, the RAAVEN and the X6 multicopter, from the sea ice within the MOSAiC Central Observatory on PS122/3, PS122/4 and PS122/5. These platforms will be deployed for up to 8 hours per day (weather permitting) and will collect regular vertical profiles of key thermodynamic properties, including temperature, humidity, pressure and winds between the surface and 2 km altitude. The DataHawk2 and the RAAVEN will additionally be used to map out spatial variability of these quantities, including around and over inhomogeneities in the sea ice. Of particular interest are periods of sampling occurring in the vicinity of breaks in the sea ice (leads), the energetic input of which into the atmosphere have been undersampled. The X6 multicopters will be operated on a regular (e.g. weekly) basis to observe the spatial variability of sea ice reflectivity and its evolution during the melt season on a scale of approximately 1 km^2. These measurements will compliment those collected using radiosondes, surface meteorological and radiometric instrumentation, helicopter-based instruments and tethered balloon systems.

Preliminary (expected) results

We anticipate collecting a rich dataset detailing the evolution of the lower atmosphere and underlying surface for 6 months of the MOSAiC cruise. These data will be used to evaluate numerical modeling tools at a variety of scales, and can be used to drive large eddy simulations to support process understanding and parameterization development. Specific topics that we anticipate evaluating include the ability of model parameterizations to represent sub-grid scale variability of atmospheric and surface properties, the influence of leads in the sea ice on the energetics and structure of the lower atmosphere over the sea ice surface in the central Arctic, and the ability of numerical modeling tools to represent the complexity of the vertical structure of the lower Arctic atmosphere.

Data management

Data produced under this study includes datasets and imagery from sUAS deployed during MOSAiC. Therefore, the most directly sharable results will include formatted and quality-controlled datasets from these activities. Processed data collected during the cruise will be formatted as NetCDF files and shared through the NSF Arctic Data Center and PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)), as appropriate. Datasets generated will be assigned a Digital Object Identifier (DOI) in order to uniquely identify these efforts.

On the ship, data collected will be stored on duplicated hard drives to prevent loss of information due to disk failure, as well as on the central MOSAiC Central Storage. Sensors will be registered in SensorWeb. The team will carry several hard drives for each 2-month leg to ensure that there are multiple copies of all collected data at any given time. At the end of each 2-month leg, data will be hand-carried back to Boulder by returning team members. Once back in Boulder, these datasets and all associated metadata will be archived and backed-up locally by IT personnel, before final processing and archival to the NSF Arctic Data Center.

All data are further handled, documented, archived and published following the MOSAiC data policy. Exceptions will to be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

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4. SEA ICE

M. Nicolaus (DE.AWI), D.K. Perovich (EDU.DARTMOUTH)

PS122/1: O. Demir (EDU.OSU), J. Haapala (FI.FMI), S. Hendricks (DE.AWI), N. Kolabutin (RU.AARI), R. Lei (CN.PRIC), I. Matero (DE.AWI), M. Oggier (EDU.UAF), I. Raphael (EDU.DARTMOUTH), J. Regnery (DE.AWI), Y. Shimanchuk (RU.AARI), G. Spreen (DE.UNI-Bremen), D. Wagner (CH.WSL)

PS122/2: D. Divine (NO.NPOLAR), P. Itkin (NO.UIT), A. Jutila (DE.AWI), C. Katlein (DE.AWI), D. Krampe (DE.AWI), G. Liston (EDU.CSU), V. Nandan (CA.MANITOBA), M. Schneebeli (CH.WSL), I. Sheikin (RU.AARI), Y. Shimanchuk (RU.AARI), J. Stroeve (COM.UCL)

PS122/3: P. Anhaus (DE.AWI), S. Arndt (DE.AWI), B. Downs (EDU.OSU), S. Fons (EDU.UMD), L. Kaleschke (DE.AWI), N. Kolabutin (RU.AARI), A. MacFarlane (CH.WSL), R. Naderpour (CH.WSL), A. Nubom (RU.AARI), F. Pätzold (DE.TUB), R. Ricker (DE.AWI)

PS122/4: G. Birnbaum (DE.AWI), D. Clemens-Sewall (EDU.DARTMOUTH), R. Dadic (SLF), M. Kaufmann (U Alaska), N. Kolabutin (RU.AARI), M. König (U Kiel), M. Mahmud (CA.UCALGARY), M. Nicolaus (DE.AWI), C. Polashenski (EDU.DARTMOUTH), J. Regnery (DE.AWI), E. Salganik (NO.NTNU), L. von Albedyll (DE.AWI)

PS122/5: G. Birnbaum (DE.AWI), P. Hwang (UK.UHuddersfield), C. Katlein (DE.AWI), B. Lange (NO.NPOLAR), B. Light (EDU.UNI-Washington), I. Matero (DE.AWI), A. Nubom (RU.AARI), M. Oggier (EDU.UAF), N. Oppelt (DE.CAU), D.K. Perovich (EDU.DARTMOUTH), R. Scharien (CA.UVICTORIA), I. Sheikin (RU.AARI), M. Smith (EDU.UNI-Washington), M. Webster (GOV.NASA)

PS122/6: T. Arponen (FI.FMI), N. Fuchs (DE.AWI), L. Istomina (DE.UNI-Bremen), N. Kolabutin (RU.AARI), J. Martinez (ES.ICM-CSIC), J. Rohde (DE.AWI), M. Schiller (DE.AWI), I. Sheikin (RU.AARI), Y. Shimanchuk (RU.AARI), NN-DEARice, NN- PROMIS6 (EDU.DARTMOUTH)

Objectives

The sea ice is an integrator between atmosphere and ocean, heavily interacting with both of them as well as the ecosystem and bio-geochemical system. As a consequence, key elements of the sea ice and snow work are distributed on all observational components and spread over all scales. Together, the implemented measurements will serve the following science objectives:

- Completely characterize the physical properties of the snow and ice cover in the MOSAiC domains, their spatial and temporal variability, and understand the processes that govern these properties
- Determine the mass and energy balances of snow and sea ice as functions of all existing snow and ice regimes
- Describe the spatial and temporal variability of ice thermodynamics and dynamics on regional scales
- Integrate sea ice measurements with other components at multiple scales
- Extend the additional process understanding from the Central Observatory to larger scales through additional studies in the Distributed Network and with model and remote sensing methods beyond this

Although the main ice camp will be installed on existing second-year sea ice that is able to support such a station, major efforts will be made to include as many sea ice and snow cover conditions, ages, and features as possible in the surrounding: new ice, refreezing leads, deformed ice, weathering and melting ice.

Mass balance of sea ice and snow

MOSAiC offers the unique opportunity to observe the evolution of the ice thickness distribution over a complete annual cycle, in dependence of wind- and current-driven ice deformation and the surface energy balance. Surface-based measurements will provide accurate information on small-scale changes due to snow drifting and melt ponding, while helicopter-borne surveys will provide links into the Distributed Network and prove provide direct links between ice deformation and changes of the thickness distribution. Floe size distribution will be derived for various studies and applications. A particular focus is snow accumulation and re-distribution and the role of energy and momentum transfer for different ice types.

Energy budget of sea ice and snow

During MOSAiC, we will investigate the seasonal cycle of ice optical properties and their variability across various surface features and ice types. This will be achieved by spectral albedo and transmission measurements. We will operate and maintain a set of autonomous observatories, perform repeated transect measurements and operate an under-ice remotely operated vehicle (ROV). These measurements will be linked to direct observations of impurities and inherent optical properties through sampling and profiling. Another objective is to up-scale these *in-situ* observations from floe scales to region al scales though merging results into surface classifications from airborne photography, laser scanning, and radar.

Ice dynamics and mechanics

Key processes of sea ice dynamics will be studied from scales from millimeters to 10s of kilometers. The observations will derive functions of deformation and shear for different ice types, including really young and new ice types. Mechanical properties of sea ice will be derived based on sea ice properties as well as seismic monitoring stations. A main programme will link bio-physical relations of pressure ridges and formation and developments of leads as major dynamical features throughout the year.

Physical properties of sea ice and snow

Physical properties are crucial elements for various studies in all teams of MOSAiC, but are also a research topic themselves. All key parameters (see below) are measured through all seasons, either through manual sampling, by specific autonomous devices at stations, or along transects. A particular aim is to obtain ground truthing data for airborne and remote sensing application, as well as to complement the mass and energy budget measurements. Winter properties as well as those during the transition phases of different seasons are of major interest, because significant changes are expected and the knowledge is still rather basic in many ways.

Melt Ponds

With the beginning of spring warming and melting, an intensive observational programme for melt ponds will be performed. The aim is to better understand formation and development processes into complete freeze-up. We will focus on optical and energy transfer issues, but also link to the ecological and biogeochemical role of melt ponds and their interaction with the surrounding surface and atmosphere.

Work at sea

The work is organized based on weekly repeat measurements following the coordinated weekly plans of all teams. The exact sequence and schedule depend on seasons (legs) and actual weather conditions. Activities will be closely coordinated within the ice group and with the other groups.

Work on ice camp

Most of the measurements and work of the sea ice team are performed within a few kilometers of the ice camp close to *Polarstern*. Sea ice and snow cover properties are observed with a huge variety of methods, covering and mapping the interfaces to the atmosphere and ocean as well as many snow and ice properties. This work is organized in tasks, mostly following methodological or structural units:

- Sea ice sampling by ice coring (Task CORES)
    a. All main ice parameters will be derived from (weekly) samples of ice cores (e.g. temperature, salinity, density, texture, O18, optical properties, micro plastics, archive core)
    b. Cores sample are processed on site in the freezer lab on board *Polarstern*
    c. Sea ice salinity is measured continuously with an Ice Harp
- Dynamics and mechanics studies (Task DYNAMICS and SEISMICS)
    a. Position buoys are deployed as a deformation array in the main ice camp and the Distributed Network
    b. Ship radar and high-resolution position (GNSS) measurements are performed and combined with stress and strain measurements though stress panels in sea ice and strain gauge sensors on *Polarstern*
    c. 3D mapping of ridges is done through bottom topography from ROV missions and surface laser scanning
    d. Seismic monitoring will be performed continuously in the main ice camp
- Helicopter borne measurements (Task HELI)
    a. Depending on weather conditions, electromagnetic (EM-Bird) surveys are carried out for sea ice thickness measurements,
    b. Airborne laser scanner for surface topography, and
    c. Helipod surveys for meteorological key parameters.
    d. Imaging systems for large scale surface properties, photo mosaics, and floe size distributions are flown over the central ice camp and beyond.
- Snow sampling and properties (Tasks PITS and LAB)
    a. Weekly to daily observations of texture, temperature, density, salinity, O18 are performed through snow pits and sampling as well as autonomous measurements
    b. More complex snow studies will investigate grain size, specific surface area through snow pits and Ice Cube measurements
    c. Stratigraphy is recorded and samples for micro-structure are retrieved from snow pits and analyzed by computer tomography on board
    d. Density, hardness, snow-water equivalent are measured through penetrometer and observed in snow pits
    e. Temperature profiles are measured through thermistor chains, manual profiles, and IR surface temperature
    f. Black carbon and chemical properties will result from samples and analysis with a Sun Photometer
- Surface topography and *in-situ* mass balance (Tasks SURFACE and STAKES)
    a. Regular and event driven surveys with terrestrial laser scanners are performed
    b. Recordings from monochromatic cameras
    c. Stakes and hot wires for surface and bottom accumulation and ablation

   d. Sea ice mass balance buoys of different types are deployed on the ice camp and in the Distributed Network

- Optical measurements (Task OPTICS)
   a. Albedo and transmission are measured along transects and from autonomous stations with broadband and spectral radiometers
   b. A Light Harp is installed to measure light conditions in and under sea ice
   c. Copter based albedo / reflectance measurements will cover optical properties on the floe scale
   d. Manual measurements with a goniometer and a hyperspectral camera will add to the optical measurements, also co-located with snow and ice sampling for optical property analysis
- Melt pond studies (Task PONDS)
   a. Pond formation, development and freeze-up processes are studied in detail by size and shape measurements in close connection to the snow and surface properties work.
   b. Geometry and coverage are monitored and selected ponds are studied in detail for optical (above, in and under) and water properties.
- Pressure ridge studies (Task RIDGES)
   a. Ridge drillings will give high resolution structural and thickness information
   b. Thermistor strings are deployed for continuous monitoring of thermal properties
   c. Coring and sampling of ridged sea ice will be performed in all seasons and combined with Borehole Jack and Zond Indentor measurements
- Observations based remotely operated vehicles (Task ROV)
   a. Optical properties of sea ice and upper ocean are recorded as horizontal and vertical profiles
   b. Basic physical (Temperature, Salinity, O18, current velocities) and biological oceanography (Chl-a, Backscatter, Nitrate) will be surveyed at the ROV sites
   c. Net hauls and water sampling is enabled by the ROV
   d. Mulit-beam sonar surveys are mostly used for bottom topography investigations
- Transects of physical properties (Task TRANSECT)
   a. Snow depth (Magna Probe) and ice thickness (ground EM) measurements are performed mostly weekly over the year
   b. Quick snow pits are performed along the transects
   c. Remote sensing instruments are also part of the measurements along transects in collaboration with Team Remote Sensing

- General snow and ice conditions (Task BASIC)
   a. General snow and ice conditions are observed with standardized bridge observations (ASSIST programme) through daily observations.
   b. Time lapse cameras are installed for seasonal monitoring, in particular a 360° panorama view camera on the crows nest of *Polarstern*.
   c. General supervision, analysis, and maintenance of ICE-buoys in the Distributed Network
   d. Maintaining the floe coordinate system (Floe Navi) is also part of the snow and ice team work.

Work on Polarstern

Different installations are necessary on *Polarstern* in order to monitor the ice camp and the surroundings of the ship (e.g. visible and infrared cameras, antennas for ground truthing of remote sensing data). A main task is the use of the ship radar for continuous monitoring of sea ice movements and deformation on scales of 5-10 km around *Polarstern*. In addition, daily observations of the ice conditions are performed following standard procedures. Main parts of the exchange of remote sensing data and drift information between land and *Polarstern* will be coordinated by the snow and ice team. On board facilities and additional lab containers are used for sample preparation, analysis and storage, in particular a freezer lab container on the working deck of *Polarstern*.

Distributed Network

A significant part of sea ice observations is performed though autonomous measurements by ice tethered platforms (buoys) in the Distributed Network. From the snow and ice perspective, main time series are gathered on

- sea ice thickness, ice growth, surface melt, bottom melt
- snow depth, accumulation, and ablation
- temperature profiles through the snow and ice
- spectral incident, reflected, and transmitted sunlight
- internal sea ice stress

These buoys are serviced as much as necessary and logistically possible. The aim is to maintain the initial network through re-deployments over the year.

Repeated visits at selected nodes of the Distributed Network will allow complementary measurements, e.g. local transects and sampling, and thus to extend transect measurements beyond the main ice camp. These stations also stand out for their distance to all main activities and thus reduced impact of *Polarstern* and the ice camp

Airborne observations

Airborne measurements will also, enable the connection of the Central Observatory with scales beyond 20 km in order to upscale the local observations and to enable estimates of regional variability. Key variables in this respect are

- sea ice thickness
- snow depth
- surface topography
- surface morphology (e.g. ridges, melt ponds)
- visible and infrared imagery
- microwave properties of sea ice and snow.

Airborne measurements are performed with helicopters from *Polarstern* whenever weather conditions allow. A main airborne measurement campaign during spring will allow long-range measurement transects between the Central Observatory and land stations.

Preliminary (expected) results

We will have a comprehensive yearlong dataset of the spatial variability and temporal evolution of the sea ice cover surrounding the MOSAiC drift station. This will include data on snow and ice morphology, physical properties, optical properties, and mass balance. There will be detailed data on spatial scales from millimeters to tens of kilometers. Data on the formation and evolution of key sea ice features such as leads, melt ponds, and ridges will be available. These datasets will useful in process studies, algorithm improvement, and model development. These results, when integrated with results from other teams will enhance understanding of the behaviour of the ice diminished Arctic Ocean system.

Data management

All data are handled, documented, archived and published following the particular MOSAiC data policy. Central elements are the MOSAiC Central Storage, data archive and publishing system of PANGAEA. (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)), buoy data are mostly available in near real time through meereisportal.de, and additional data access is given through different national data archives and repositories.

References

NONE

5. OCEAN

B. Rabe (AWI), Celine Heuze (SE.GU)

I. Fer (NO.UIB, not on board), Z. Koenig (NO.UIB), A. Olsen (NO.UIB, not on board)

M. Granskog (NO.NPOLAR, not on board), M. Muilwijk (NO.NPOLAR), A. Sundfjord (NO.NPOLAR, not on board), J. Allerholt (DE.AWI), Y.-C. Fang (DE.AWI), R. Graupner (DE.AWI), M. Hoppmann (DE.AWI), M. Janout (DE.AWI, not on board), T. Kanzow (DE.AWI), D. Kuhlmey (DE.AWI), I. Kuznetsov (DE.AWI), J. Regnery (DE.AWI), K. Schulz (DE.AWI), S. Tippenhauer (DE.AWI), M. Vredenborg (DE.AWI, not on board)

B. Shaw (EDU.NPS, *Akademik Fedorov* only), T. Stanton (EDU.NPS, *Akademik Fedorov* only), V. Morholz (DE.IOW), H. Liu (CN.SJTU), C. Mertens (DE.UNI-Bremen, not on board), M. Rhein (DE.UNI-Bremen, not on board,), N. Sukhikh (DE.UNI-Bremen), M. Walter (DE.UNI-Bremen, not on board), Y. C. Bai (CN.SIO, not on board), H. L. He (CN.SIO), L. Lin (CN.SIO, *Akademik Fedorov* only), Y. Kawaguchi (JP.UTOKYO), C. Basque (EDU.WHOI, *Akademik Fedorov* only), A. Davies (EDU.WHOI), R. Krishfield (EDU.WHOI, not on board), J. Toole (EDU.WHOI, not on board), Xiaobin Ma (CN.MNR, *Akademik Fedorov* only), Bin Kong (CN.MNR), Yan He (CN.MNR, not on board), Tao Li (CN.OUC, *Akademik Fedorov* only), Jialiang Zhu (CN.OUC, *Akademik Fedorov* only)

Outline

The sea ice in the Arctic Ocean is changing under global warming, and there is evidence that the inflow of Atlantic water (AW) has reduced the upper ocean stratification enough, such that convective wintertime deepening of the mixed layer may have caused a sizable upward heat flux in parts of the Eurasian Basin. In the more permanently ice-covered central regions of the Arctic Ocean, it is thought that the halocline still prevents vertical mixing and thus, strong upward heat fluxes year-round. However, wintertime measurements hardly exist.

Near-surface trapping of heat during the late summer has been of growing importance as the influence of solar radiation entering the ocean increases with snow melt, melt-pond formation and increasing open water fraction of the ice-pack.

Observing a full seasonal cycle as well as studying the ice-ocean-atmosphere system in the Arctic at shorter timescales using an extended set of parameters will be extended in an unprecedented manner by MOSAiC. The specific focus of the OCEAN team is here on the physical parameters of the upper ocean, bounding on the sea-ice and the atmosphere, and the interaction with the lower parts of the water column. This will not only improve our understanding of the physics of the upper ocean at times where no or few measurements exist and throughout a full seasonal cycle but also improve our understanding of feedbacks with the sea-ice/snow, the lower atmosphere, biogeochemical processes and the ecosystem.

The overall aim of our work is to understand, throughout all seasons, the dynamics in the upper Arctic ocean mixed-layer and the halocline on the scale of turbulent vertical mixing to the (sub)mesoscale, embedded in the Arctic system of large-scale advective pathways of different water masses. Specific foci include how these dynamics feedback with different ice conditions, such as ridges or open water leads, and with regional variations in water masses and background stratification throughout the water column.

The properties of the turbulent boundary layer at the sea ice – water interface have crucial impacts on the sea ice and the structure of the boundary layer. The strength of turbulent mixing controls the heat flux, as well as the buoyancy flux in the boundary layer, but also ice bottom melt rates (Keitzl et al., 2016) and brine release (Peterson, 2018). In turn, these processes modify also the turbulence, which is generated mainly by current shear or convection due to heat flux.

(Sub)mesoscale variability is capable of inducing substantial vertical velocity (several meters per day) from below the ocean mixed layer. In the seasonally ice-covered ocean, this process is more complicated by modulation of sea ice within the evolving ice-ocean boundary layer. This ocean-ice coupled system has been investigated near marginal ice zones, where (sub)mesoscale currents interact with ambient mesoscale field and result in sea ice aggregation and advection (Manucharyan and Thompson, 2017). However, little is known about how (sub)mesoscale variability influence the upper ocean in the central Arctic. Moreover, an appropriate parameterization of such features in a general circulation model (GCM) is still challenging.

Trace gases that do not interact biogeochemically in the ocean are valuable tools to assess the role of physical processes. Inactive trace gases come in two classes: The first are the transient tracers like CFCs, SF6 and tritium (^{3}H), that are anthropogenic in origin and have changing atmospheric concentrations with time. The second are the steady state tracers like the noble gases and their isotopes (^{3}He, ^{4}He, Ne).

We will carry out observations with several specific objectives using a multitude of *in-situ* sensors and sampling devices, as detailed in the subsections below. In addition to manual measurements, several buoy systems measuring autonomously in the ice camp and within the Distributed Network around *Polarstern* will provide data at daily or shorter intervals. The distribution and parameters of those systems are briefly described in the sections Ice Camp and Distributed Network.

Several different projects contribute to the MOSAiC OCEAN team, as detailed in separate documents. All current contributors, participating or “not on board”, are listed at the beginning of this chapter together with their corresponding affiliations. Further projects, not listed here, are expected to benefit from MOSAiC observations and contribute to subsequent analysis. In particular, there is strong cooperation by team OCEAN with the other MOSAiC teams, both *in-situ*, remote sensing and modelling, to study the coupled system in an interdisciplinary context.

5.1 Ocean state, water mass tracers and advection

Objectives

One objective is to measure the ocean state variable temperature and salinity at different depths throughout the water column throughout a full seasonal cycle, concurrent to measuring and sampling further ocean parameters. This is crucial to determine the local background conditions, such as upper ocean stratification and the potential for melting sea ice; further, they allow to locally identify water masses, advected within an Arctic-wide system of pathways, and facilitate the analysis of further parameters. These include CFC and SF6 to facilitate more detailed water mass analysis, and macronutrients to study the corresponding small-scale vertical fluxes and large-scale pathways. Observations of other tracers, such as d18O, and macronutrients, are detailed in the chapters on ECOSYSTEM and BIOGEOCHEMISTRY.

In addition, we want to determine local horizontal advection and vertical shear on different vertical scales in the water column.

Further objectives are focusing on the intermediate and deep ocean:

1. To determine the extent and path of the waters coming from Fram Strait, the Siberian shelves, and those formed locally by open ocean deep convection;
2. To quantify the variability of deep Arctic water properties and its sources, and identify the drivers of this variability.

Work at sea

Two CTD/rosette systems will allow weekly and higher frequency profiling and sampling from the ship through a large ice hole (full-depth profiling) and from a tent (OCEAN City shelter) installed above an ice hole about 300 m away in the ice camp (profiling to a depth of 1,000 m). Both systems will be equipped with Seabird CTD instrumentation, including duplicate temperature, conductivity and oxygen sensors. A variety of other sensors are planned to measure, for example, Photosynthetically Active Radiation (PAR); fluorescence of Colored Dissolved Organic Matter (CDOM) and Chl *a*; dissolved methane; dissolved nitrate; and beam transmission / absorption. Data logging and control is facilitated by Seabird deck units and conducting cables.

The ship-based system will be equipped with 24 bottles with a volume of 12 l each, whereas the OCEAN City system will have 12 bottles with 5 l each.

A backup for the OCEAN City system will be available from PS122/2 in the form of a Hydrobios rosette equipped with 6 bottles, 4.5 l each and a Sea&Sun unpumped CTD, also allowing live data logging and control.

Additional, three mobile CTD systems will allow to measure profiles from any location on the ice reachable by skidoo or helicopter: one mobile winch system allows full-depth profiles with a self-recording CTD; a lighter system with a fishing-rod winch allows profiles to 700 m with a small, light-weight self-recording CTD; a third system allows rapid profiling and live data logging of the upper 1,000 m using an expendable probe.

Several Acoustic Doppler Current Profiler (ADCP) systems allow observing horizontal current velocity and vertical shear on scales of few centimeters to 10 m to depths of a few meters to 500 m, respectively. These systems are mounted in the keel of the ship and under the ice in the ice camp. These systems will be operated continuously and provide time-mean velocity profiles at intervals of a few minutes.

Several autonomous buoys systems will observe temperature, salinity and pressure at different locations throughout the Distributed Network. These include CTD profilers: WHOI-ITP, SIO-ITP, FIO-ITP and D-TOP. Several systems will have CTD instruments installed at fixed levels (depths). Measurements of current shear in the upper 80 m will be provided by ADCP in Autonomous Ocean Flux Buoys (AOFB's, see also 5.2) three remote sites and the ice camp.

CFC/SF6 will be sampled during the weekly full-depth CTD/rosette casts and subsequently analyzed in a lab on land (see also 5.2).

One autonomous bottom temperature/pressure recorder 'Tpop' will be deployed every two weeks from PS122/1 to PS122/4, totaling 16 deployments.

Preliminary (expected) results

We expect a unique dataset of ocean state across the Eurasian Basin throughout all seasons, concurrent with various biogeochemical and biologically relevant parameters. After analysis of the CFC/SF6 samples by the University of Bremen (team of Maren Walters / Christian Mertens), the 'age' of the water will be known (Tanhua et al., 2009), from which its path can be inferred.

The current measurements will provide a regional distribution of currents and, together with the ocean state / tracer measurements and historical data, improve our understanding of large scale advective pathways of water masses and biologically relevant substances in the upper 500 m.

The Tpops will measure the temperature and pressure once per hour for two years, before automatically burning their link to their anchoring weight, float to the surface, and send me their data via iridium. That will give us the first ever time series, in the entire deep Eurasian basin, covering the subdaily to seasonal time scales.

Data management

All data will be subject to post-processing and careful quality checks. Final data will be stored at Pangea (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) or otherwise made publicly available, in accordance with the MOSAiC Data Policy.

All data are handled, documented, archived and published following the MOSAiC data policy.

5.2 Small scale turbulence, mixing and vertical fluxes

Objectives

Advance our understanding of the vertical mixing processes, their role for the heat, nutrients and other (mass) parameters in the Arctic Ocean. The context of seasonality and feedbacks with different parts of the coupled atmosphere-ice-ocean system is of particular importance. This includes the effect of enhanced melt or storms. The aim is to obtain high resolution time series data of turbulence and the current field in the upper ocean (mixed-layer, halocline/pycnocline and warm Atlantic Water) year-round, with several projects focusing on a particular season or specific ice conditions.

One focus is the ocean boundary layer next to the sea ice – water interface year-round. In particular, during the Arctic winter we want to improve the understanding of heat flux and brine release from young sea ice and leads. A further focus is the role of sea-ice ridge keels on upper ocean mixing.

A more ecosystem-related aspect is to quantify vertical mixing and nutrient fluxes before, during, and after the spring and summer blooms (PS122/5 and PS122/6) in order to understand physical mixing processes and their role in sustaining subsurface blooms in a changing Arctic.

To better understand of how solar heat is deposited in the upper ocean we want to measure the inherent optical properties (IOPs, absorption/attenuation) during different seasons with solar radiation. In particular, we want to understand the response to sea ice melt stratification in the Arctic basin, as very limited observations exist (Granskog et al., 2015). Further, phytoplankton blooms are known to significantly alter the absorption of solar radiation and, thus, upper ocean heating (Taskjelle et al., 2017).

Work at sea

We will carry out measurements of ocean microstructure, rapidly varying shear and temperature, through the ice hole in OCEAN City several times per week to obtain estimates of ocean turbulence and fluxes. These will be complemented by profiles of other quantities, for example, dissolved nitrate in collaboration with the ECOSYTEM team in order to quantify vertical nutrient fluxes. The turbulence data will be obtained by different models of MSS microstructure profilers. All will be equipped with fast temperature, shear and oxygen sensors as well as a standard Seabird CTD; additional instruments will also measure Chl *a* fluorescence and turbidity. Further dissipation measurements will be made in the upper 80 m up to the ice-water interface using an uprising vertical microstructure profiler (VMP).

In addition to manual profiling, we will install instrumentation under the ice in OCEAN and MET cities to record data continuously at high temporal resolution (1 to 512 Hz for turbulence measurements, minutes for background measurements), a thermistor chain (upper 200 m), a temperature microstructure probe (at 60 m), and co-located CTD/pCO2/turbulence velocity sensors (at 30, 50, 90 m).

During PS122/2, the current field in the boundary layer will be observed with a special 1.2MHz 54°ADCP that allow the concurrent observation of currents and turbulence. Together with an MSS profiler deployed along-side this will allow to gather several 4 to 6 hour time series.

We will deploy high-resolution 3D current meters nearby ridge keels on central ice floe to measure turbulence by a ridge keel during PS122/2 - PS122/5(PS122/6). These observations will be combined with the current and turbulence observations further away from the ridge (see above) to examine differences between ridged ice and more level ice. More intensified observations will be done during part of the time.

We will carry out continuous, direct measurements of turbulent diffusivity and heat fluxes in the pycnocline; heat, salt, and momentum fluxes near the ocean / ice interface; and cm-resolution profiles of temperature, salinity, and optical properties in the under-ice boundary layer. This will be facilitated by using four Autonomous Ocean Flux Buoys (AOFB's), deployed at three sites in the Distributed Network about 10-15 Km from the *Polarstern*, with one at the central site in adjacent to the atmospheric boundary layer measurements at "MET City". These ocean instrument systems will provide measurements at intervals of 2 hours.

We use a further approach to obtain vertical heat fluxes by combining integral estimates from measuring dedicated helium and neon isotopes, tritium, CFC, and SF6 water samples. Weekly trace gas sampling from will cover the upper 400 m of the water column (in addition to CFC/SF6 for the full water column, see also 5.1). The sampling frequency will be increased during events to characterize the conditions at the start and at the end and the temporal evolution. Noble gases are collected in copper tubes, CFC/SF6 samples are collected in glass ampoules. In total 900 noble gas and 900 CFC/SF6 samples will be taken. Noble gases and CFC/SF6 samples will be analyzed in the IUP lab.

We will carry out weekly profiles of water inherent optical properties from Ocean City in spring and summer (PS122/4 - PS122/6) using an *in-situ* absorption meter.

A hybrid acoustic and optical mapping system in the ice camp will map the detailed evolution of the basal morphology over the year-long experiment, identifying changes in hydraulic roughness and other features that influence ice/ocean coupling.

Additional measurements will be carried out during lead events every few weeks, together with other MOSAiC teams. These observations will include profiles of turbulent microstructure, vertical shear of horizontal velocity and tracer sampling in the vicinity of the lead.

Preliminary (expected) results

From the further manual profiling and autonomous observations we will quantify vertical fluxes in the upper water column and relate the variability to environmental conditions (external forcing, wind, tides, ice conditions, ocean circulation, submesoscale processes). For example, we will describe the role of ocean heat flux in modulating the sea ice thickness and area.

The intensified under-ice boundary layer measurements in the ice camp will provide information about the properties and evolution of the turbulent boundary layer in the early Arctic winter.

Tracer derived estimates of fluxes in and out of the mixed layer are an integral over the involved time scales. The effects of events are calculated from the difference in the tracer distribution before and after their occurrence. The trace measurements will be used to estimate the impact of events on the vertical heat fluxes across the base of the mixed layer.

The ridge measurements are expected to a give a novel time series of mixing below sea ice nearby a sea-ice ridge over nearly a full annual cycle, with more detailed measurements for part of the time.

The profiles of inherent optical properties of the upper water column will lead to an unprecedented data set on the evolution of vertical absorption in the upper ocean and, thus, provide insights into the role of sea-ice melt and phytoplankton on solar heating in the central Arctic.

The concurrent ocean state and nutrient measurements, including continuous nitrate (sensor) profiles, will allow the calculation of vertical nutrient fluxes throughout all seasons.

Extended observations during PS122/5 and PS122/6 will generate a several month-long record of vertical nutrient fluxes, which may allow to single out physical events as mixing drivers (eddies, storms, leads) and quantify their importance in triggering and sustain blooms. Further, advection is assumed weak in the Central Arctic, which may allow a one-dimensional view of the evolution of the spring bloom and the associated nutrient dynamics, and hence provides a good basis for one-dimensional model experiments.

The results of our observations will be used to validate and improve the ocean components of climate models and, specifically a one-column atmosphere-ice-ocean coupled model.

Data management

All data will be subject to post-processing and careful quality checks. Final data will be stored at Pangea (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) or otherwise made publicly available, in accordance with the MOSAiC Data Policy.

All data are handled, documented, archived and published following the MOSAiC data policy.

5.3 Mesoscale dynamics and variability

Objectives

Our objectives are to observe the evolution of the upper ~100 m thermohaline field within a semi-Lagrangian framework. Together with other observations, this will improve our understanding of upper ocean (sub)mesoscale variability, subject to feedbacks with the atmosphere/ice above and biological / biogeochemical processes.

Work at sea

An important element for studying (sub)mesoscale variability will be conducted by deploying autonomous temperature and salinity (T/S) buoys radially at up to eight sites in the Distributed Network. The CTD devices will obtain measurements at several depth levels in the upper ocean with high temporal resolution. We will monitor these data live on the ship in near real-time to allow detection of (sub)mesoscale events and intensified observations at the ice camp.

Preliminary (expected) results

We expect to observe ubiquitous horizontal density gradients accompanied by (sub)mesoscale currents due to baroclinic instability, and footprints of (sub)mesoscale variability should be detected. The current and turbulence observations mentioned in 5.1 and 5.2 are important for the interpretation of these T/S data.

Data management

All the data we will acquire, as described in 5.1, 5.2 and 5.3, will be transmitted on a regular basis either IRIDIUM (satellite transmission) to land and in reduced form back to the ship for operational purposes. A subset of these will be transmitted to land via the ship's satellite connection to allow expert advice on operations from land. Some devices require regular manual download of the data in the field, either via a network (LAN) connection or by recovery and redeployment.

In particular, the autonomously acquired T/S data will be transmitted live via IRIDIUM to land and back to the ship to allow near real-time monitoring of these parameters. For this purpose, we will use a custom configured web version of Ocean Data View, specially developed by the group of Rainer Schlitzer at AWI, on-board.

The noble gas and CFC/SF6 data will be made available to all participants, and submitted to the PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) data base two years after the cruise. The Tpops data are expected earliest in summer 2022, but that will depend on whether the devices will be trapped under ice.

All data will be handled according to the MOSAiC data policy.

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6. BIO-GEOCHEMISTRY

E. Damm (DE.AWI), B. Loose (EDU.URI)

6.1 Greenhouse gases

6.1.1 Fate and pathways of trace gases (CH_4, N_2O and CO) in and between sea ice and surface water

E. Damm (DE.AWI), M. Angelopolus (DE.AWI), B. Delille (BE.ULIEGE), B. Koch (DE.AWI), F. Pätzold (DE.TUB), A. Rinke (DE.AWI), T. Sachs (DE.GFZ), J. Verdugo (DE.AWI), L. Zhan (CN.POLAR)

Elevated atmospheric methane concentrations over open leads and regions with fractional sea ice cover (Korts et al., 2012) point to sea ice implications in the role of transferring methane from the oceans to the atmosphere. A cascade of feedback processes triggered by freezing and melting events of sea ice induces seasonally the uptake of methane from sources remote from the locations where methane is released (Damm et al., 2015, 2018). We consider the following pathways: direct interactions, i.e. from ice and snow to surface water and indirect interactions, where trace gases circulate through more than one environment before leaving to the atmosphere. Hence, our project is closely linked to the planned detailed seasonal tracing of sea-ice processes by stable water isotopes H_2O ($\delta^{18}O$ and δD) (see Bauch et al.). We focus on alterations in the isotopic composition of methane along these pathways, mainly by the kinetic isotopic fractionation effect. This fractionation might initiate modifications in the isotopic signature compared to the initial source-signature, which are not considered yet. Those processes might encourage a misinterpretation and finally misleading source identification of Arctic emissions. Isotopic shifts by microbial induced methane oxidation will be considered within the Loose/Bowmann project (see below). Tracing the isotopic signature of methane from the source to the final sink will be completed by the analyses of air samples (see Lampert et al. project).

Rapid environmental change across the Arctic Ocean has the potential to alter also the cycling and sea-air exchange of nitrous oxide (N_2O) and carbon monoxide (CO). Understanding these potential effects is limited by a lack of Arctic Ocean N_2O and CO observations with sufficiently high spatial and temporal resolution.

Work at sea

We will measure dissolved gases (CH_4, N_2O, CO) in surface water (ocean, melt ponds, brine) and sea ice. Ocean water sampling will occur from the Ocean City rosette weekly. This schedule will allow collecting a year-round time series for the trace gas-budget calculation.

Additional water sampling will take place for process studies under special consideration of freezing and melt effects. Hence, sampling will happen with the highest vertical resolution in the sea ice affected water, while below this horizon at standard 50 m depths down to about 300 m or the inflowing Atlantic water. The selection of sampling depths will be continuously adapted to gradients in the fluorescence signal, the O_2 sensor signal and the concentration profiles from the weekly measurements.

Sea ice sampling ice will start with an ice floe exploration during PS122/1. After detecting the main ice types, relevant positions for the year-round time series will be selected. Planned are at least two positions. Selection priorities include the age and structure of sea ice, as well as the source region of sea ice, i.e. shelf/polynya ice from Siberia and/or Alaska and freeze up sea ice. In addition, at all legs sea ice sampling will occur during/after events and at the Distributed Network stations.

Sea ice will be sampled by taking cores with a standard Kovacs ice corer. Afterwards, the ice cores will be sectioned in the freeze container and melted at 4°C in vacuumed bags. Methane concentration will be measured on board by a gas chromatography (GC) device equipped with a flame ionization detector (FID). The δ^{13}C signature of methane will be analyzed with a PICARRO 2132 on board and on selected samples on the mass spectrometer in the home lab. CO and N_2O will be partly analyzed on board by a GC with a Helium discharge detector (HeD) and partly in the home lab.

Preliminary (expected) results

By combining a year-round of observations we are able to evaluate how seasonal variability in physical and biogeochemical regimes affects trace gas distributions (CH_4, N_2O and CO) and sea/ice-air fluxes.

Data management

Data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).

All data are handled, documented, archived and published following the MOSAiC data policy.

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6.1.2 Tracing the methane δ^{13}C signature and concentration in the lower Troposphere

A. Lampert (DE.TUB, not on board), F. Pätzold (DE.TUB), E. Damm (DE.AWI), A. Rinke (DE.AWI), H. Chen (NL.RUG, not on board), S. van Heuven (NL.RUG, not on board), T. Sachs (DE.GFZ)

Objectives

To complete the picture of methane transport air samples are taken with two different airborne systems and analyzed for methane δ^{13}C signature and concentration. Together with meteorological measurements the linking mechanisms of methane transport from sea ice/sea water into the atmosphere, depending on atmospheric stability and ice conditions shall be identified using the δ^{13}C signature as tracer.

Work at sea

Two very different airborne systems will be used to take air samples and other meteorological data: The UAS ALICE and the helicopter towed system HELIPOD.A specialized air-sampling quadrocopter ALICE will be used to take discrete and continuous air samples up to 1,000 m above ground. Additionally, basic meteorological data are continuously measured and a dedicated mapping camera records the surface properties. Twelve plastic bags instead of the rigid glass flasks will be used. An AirCore was integrated in addition (Truls et al., 2018).

The air-sampling quadrocopter is scheduled for three actions per week during PS122/3 and PS122/4, each action including two flights. The main focus is on lead events. In case of absence of leads a regular monitoring at the Central Observatory will be done.

The helicopter towed system HELIPOD offers the same air-sampling devices but is much more extensively equipped with meteorological sensors and an optical methane concentration sensor. A description of the HELIPOD can be found in the ATMO part of the expedition programme.

Once per week the HELIPOD shall be flown on PS122/3 and PS122/4 during daylight. Trajectories and air-sample distribution will be chosen depending on the current meteorological and ice situation. Long distance transects, vertical profiles and locally stacked legs can be combined to observe potential local sources as well as fluxes over homogenous terrain. The methane $\delta^{13}C$ signature and concentration of the air samples will be analyzed with the PICARRO 2132 on board.

Preliminary (expected) results

The measurements shall provide data to identify the linking mechanism of methane transport from sea ice/sea water into the atmosphere, depending on atmospheric stability and ice conditions.

Data management

Data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).

All data are handled, documented, archived and published following the MOSAiC data policy.

References

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6.1.3 Quantifying microbial controls on the annual cycle of methane and oxygen within the ultraoligotrophic Central Arctic

J. Bowman (EDU.UCSD), B. Loose (EDU.URI), A. D‘Angelo (EDU.URI), E. Chamberlain (EDU.UCSD)

Objectives

We will undertake a comprehensive, mechanistic evaluation of oxygen and methane production, consumption, and transport in the central Arctic across the annual cycle. We will measure the rates of net community production (NCP), methane oxidation and production, bacterial respiration (BR) and bacterial production (BP) in the central Arctic from the air-ice interface through the photic zone. These measurements will be used to functionally constrain metabolic processes in two regional models of the Arctic and to produce model-based budgets of methane and net community production for the central Arctic. Through this effort we will better anticipate future change to the high Arctic marine ecosystem, and better understand the role of these processes in the current climate system. The proposed work will directly inform

Questions 4 and 5 above of the MOSAiC Science Plan. To carry out these studies we will complete the following objectives:

- Objective 1 – Make continuous surface measurements and bi-weekly discrete profiles of seawater O_2, Ar, and N_2 by Membrane Inlet Mass Spectometry (MIMS).
- Objective 2 – Make continuous surface and bi-weekly discrete profiles of seawater CH_4, CO_2 concentration, and stable isotope ratios using Cavity Ring Down Spectrometry (CRDS).
- Objective 3 – Conduct bi-weekly sampling for microbial community structure (16S/18S rRNA gene analysis).
- Objective 4 – Make discrete bi-weekly profiles of these same variables within sea ice, from cores collected at the MOSAiC Central Observatory.
- Objective 5 – Conduct bi-weekly measurements of BP, and BR. Bacterial and phytoplankton abundance and PP will be provided for these same samples by collaborators as noted above.
- Objective 6 – Experimentally determine methane oxidation (MO) and methane production (MP), and evaluate the microbial community structure, gene expression, and oxidation potential using elevated methane in select incubations.
- Objective 7 – Identify patterns of expression for genes involved in methanotrophy, and use metatranscriptomics to identify genes differentially expressed under high methane conditions.
- Objective 8 – Through modeling, identify the microbial taxa and physicochemical conditions that best predict the key ecosystem functions of methane production, methane oxidation, BR, CR, BP, NCP, nitrification, and DMS production.

Work at sea

We will measure dissolved gases (CH_4, O_2 and Ar) in seawater water and in selected sea ice cores. Seawater sampling for ambient methane concentration will take place weekly; water sampling for methane oxidation rate will occur biweekly. Net community productivity will be estimated from continuous seawater sampling and from discrete vertical profiles using the AWI Membrane-Inlet Mass Spectrometer.

Sea ice will be sampled by taking cores with a standard Kovacs ice corer. Afterwards, the ice cores will be sectioned in the freeze container and melted at 4°C in vacuumed bags. The $\delta^{13}C$ signature of methane and carbon dioxide will be analyzed with a PICARRO G2201i on board.

Preliminary (expected) results

We intend to interpret the MOSAiC drift measurements in a spatially-varying as well as time-varying perspective. The distributed measurements of methane oxidation will be used to constrain subsurface methane oxidation in the Arctic. Year-round observations will allow us to observe the seasonal transitions in photosynthesis, respiration, and oxidation together with the microbial communities that drive these gas transformations.

Data management

Data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) and/or on arcticdata.io according to the protocol agreed upon between these two archives and in accordance with the data policies of the NSF Office of Polar Programs.

All data are handled, documented, archived and published following the MOSAiC data policy. Exceptions will to be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

References

NONE

6.1.4 Methane flux (chamber) measurements

D. Nomura (JP.HOKKAIDO), B. Delille (BE.ULIEGE), J. Inoue (JP.NIPR, not on board) and BGC team (for year-round service)

Objectives

Sea ice has rarely been considered in estimates of global biogeochemical cycles, especially gas exchanges, because of the assumption that, in ice-covered seas, sea-ice acts as a barrier for atmosphere–ocean exchange. However, recent work has shown that sea ice and its snow cover play an active role in the exchange of gases between the ocean and atmosphere (Nomura et al., 2013; Delille et al., 2014). However, the lack of information for the winter-time and long term (e.g. year-round) sea ice biogeochemistry was pointed out, due to the difficulty to acquire data under harsh weather conditions and to keep the ice station for long time. Therefore, we will examine the year-round air–sea ice CH_4 flux in addition to CO_2 flux in the central Arctic Ocean.

Work at sea

Air–ice CH_4 flux will be measured by the enclosure chamber system once a week during the whole MOASiC survey at sea ice coring site. Chamber system is composed by LI-COR 8100-104 chamber, LI-8100A soil CO_2 flux system, and Los Gatos Research Ultraportable Greenhouse Gas Analyzer. Fluxes are first measured over the bare sea ice after removing the snow (about 2 hours), and then, over snow on sea ice on the same area (about 5 hours). If any frost flower, melt pond, lead, refrozen lead develop, measurement could be carried out as “event” at other day of ice coring. Flux measurement will be done at same day as the ice coring near the sea ice coring site to constrain the relationship between fluxes and ice/snow CH_4 concentration. Discrete measurement of N_2O fluxes will be carried using a stainless-steel Teflon coated manual chamber and pre-vacuumed air bottles. These measurements will be coordinated with snow investigators in order to achieve a detailed description of snow structure. A floating support will allow to deploy chamber over melt ponds. In addition, chamber measurements of air–ice CO_2 and CH_4 fluxes will be compared with the eddy covariance carried out by the Atmospheric group. Chamber measurements will allow to address spatial variability within the footprint of eddy covariance measurement and therefore to improve our understanding of eddy covariance results.

Preliminary (expected) results

Our air–ice CH_4 flux will provide information about the role of sea ice formation and decay for CH_4 cycle in the ice-covered Arctic Ocean. Air–ice CH_4 flux will be changed depending on 1) CH_4 concentration within sea ice and 2) ice surface condition (snow condition) etc. For 1), we will take brine and sea ice core samples and try to understand process to decide the CH_4 concentration within sea ice. For 2), we will compare air–ice CH_4 flux between the measurement on sea ice and snow in order to clear up the effect of snow on sea ice for gas exchange process.

Data management

All data collected and generated by this project will be made publicly available via the World Data Center PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de).

All data are handled, documented, archived and published following the MOSAiC data policy.

References

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6.1.5 *In situ* measurements (CH_4, N_2O, CO and CO_2) in sea water and air

L. Zhan (CN.POLAR), L. Wang (CN.BNU) and BGC team (year-round service))

Objectives

With continuous global warming recently, a sustained decline of sea ice extent was observed in the Arctic Ocean, which may have significant impact on CH_4 and CO_2 exchange between ocean and atmosphere and global carbon cycles, such as enhancing its sea-air flux. In addition, sea ice absorbs methane in atmosphere by photochemical and biochemical oxidation. However, there impact is still not well understood. With the increase of global atmospheric temperature, and the melting of Arctic sea ice, sea ice role of shielding and consumption of methane is weakening, this area may turn into an important source of atmospheric CH_4, which can have significant impact on regional and global carbon cycles and climate systems. Therefore, we hope to quantitatively estimate the amount of greenhouse gases in the Arctic Ocean through large-scale underway observations. We use an underway system to measure the surface water greenhouse gases partial pressure continuously, the system provide data of the CH_4, N_2O, CO, and CO_2 concentration in surface water, and the partial pressure in air. We trace the dynamic of the greenhouse gases distribution and exchange with a high resolution focused on: 1) The high-resolution change of the greenhouse gases distribution pattern during sea ice formation and melting; 2) the variabilities of greenhouse gases beneath the winter sea ice and its implication for their circulation.

Work at sea

We will measure CH_4, N_2O, CO and CO_2 in the atmospheric boundary layer and the surface water using a Greenhouse gases underway observation system. The system will be installed on the *Polarstern* and carry out one whole cruise observation. The system consists of Los Gatos N2O/CO-30-EP and GGA-34r-EP analyzers and an integrated system, which can be programmed to take surface water sample and air sample for analysis in certain interval.

Arctic Ocean surface water methane, carbon dioxide fluxes and isotopic signature were measured concurrently using an integrated nozzle-type equilibrator (EQ) and cavity ring-down spectrometer (CRDS) enabling high spatial resolution measurements. Stable carbon isotope values measured with the PICARRO -2201i were calibrated against standard gases to obtain accurate $\delta^{13}C$ values of surface water methane (±4‰ at 2 ppm; ±1.5‰ at 5 ppm) and CO_2 (±1.5‰). The gas concentration data were combined with meteorological (wind speed, air temperature) and sea surface water environmental parameters (salinity, water temperature). To constrain biological activity in surface water, additional environmental parameters (dissolved oxygen (DO), pH, fluorescent dissolved organic matter (fDOM)) were measured in seawater pumped aboard the ship by a Multi-parameter water quality monitor (YSI EXO2).

We also focus on the measurements of methane profile in several sites by sensitive methane sensor (METS, sensitive) on several ice stations in the Arctic Ocean. Methane sensor combined with CTD, falling below the water at a certain speed (xx m/min), the maximum depth of measurement of methane profile is about 250 m.

Preliminary (expected) results

The aim of this work is to reveal the source sink characteristics of the Arctic Ocean. The effect of sea ice forming and melting on N_2O distribution pattern will be studied and the air-sea flux of N_2O during sea ice forming and melting process will be evaluated.

Over all the collected data shall lead to a better understanding of temporal-spatial variations of methane, carbon dioxide fluxes and isotopic signature in the surface water of Arctic Ocean.

This will allow comparisons of methane flux in sea ice cover and open water ocean.

Data management

Data will be stored at the PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).
All data are handled, documented, archived and published following the MOSAiC data policy.

References

NONE

6. 2 Organic sulfur cycling in arctic sea ice and seawater

J. Stefels (NL.RUG), M. van Leeuwe (RUG), D. Bozzato (RUG), H. Schäfer (UK.WARWICK, not on board), A. Webb (UK.WARWICK), Y. Chen (UK.WARWICK, not on board), J. Todd (UK.UEA, not on board)

Objectives

The aim of the teams led by Stefels and Schäfer is to carry out a detailed analysis of the organosulfur cycle and its microbial players in the Arctic Ocean over the course of the MOSAiC campaign. The work will combine measurement of concentrations of dimethylsulfoniopropionate (DMSP), dimethylsulfide (DMS) and dimethylsulfoxide (DMSO) transformation rates of these compounds and identification of the microorganisms (microalgae, bacteria, archaea) driving these processes using molecular biological approaches. We will address how seasonality, sea ice and water characteristics in the Arctic Ocean affect the microbial cycling of organic sulfur compounds that are key agents in formation of secondary organic aerosol in the Arctic and thus contribute to regional climate feedbacks in the Arctic climate system. It is therefore of particular interest to better estimate the magnitude and rates of the microbial processes that drive the biosynthesis, and degradation of DMS and related compounds DMSP and DMSO in Arctic samples and to relate the data obtained on the flux of the compounds in the organic sulfur cycle to the relevant microbial pathways and populations. This will involve measurement in sea ice and sea water of key organosulfur species including DMSP, DMS and DMSO during the MOSAiC Expedition. The dynamics of the microalgal community throughout the seasonal changes will be explored through the use of HPLC and microscopic analysis. All the parameters will be combined in multivariate statistics to determine the processes affecting DMS, DMSP and DMSO concentration and the changes we will observe throughout the year.

Work at sea

Work onboard *Polarstern* will include sampling of sea ice, under ice water, sea water and potentially, on occasion, under ice biota and snow. Samples will be analyzed for the concentration and rates of processes transforming organosulfur compounds using Proton Transfer Reaction Mass Spectrometry (PTRMS) with addition of stable isotope labelled tracers of DMSP, DMS, and DMSO during dedicated incubation experiments (Stefels et al., 2009). In case of sea ice, this will be achieved during an isohaline melt procedure. Melted samples will be filtered to preserve the microbial (bacterial and microalgal) biomass and filters will be stored at -80 for subsequent work in the home laboratory as described above. Samples collected for molecular processes and community dynamics will be processed in our home laboratories. DNA and/or RNA will be extracted and the taxonomic and functional diversity of the microbial populations will be determined based on sequencing of ribosomal RNA genes and a number of genes encoding enzymes of DMSP synthesis and degradation, DMS and DMSO cycling, and MT oxidation. many of which we have previously described (e.g. Curson et al., 2011; Lidbury et al., 2016; Eyice et al., 2018; Carrión et al., 2015).

Expected results

- Standing stocks of organosulfur compounds in sea ice and seawater samples (PS122/3 - PS122/6), total DMSP concentration (PS122/1 and PS122/2)
- Process rates of DMSP assimilation, DMSP to DMS degradation, DMSO production
- Identification of algal and bacterial DMSP producers and microbial populations degrading DMSP, DMS and DMSO.

Data management

All data are handled, documented, archived and published following the MOSAiC data policy. Once processed and quality controlled all PTRMS will be published in PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) to be available for the entire MOSAIC community and following publication for the global scientific community. Data for taxonomic and functional diversity specifically in the incubations carried out on board will also be submitted with environmental metadata to the National Center for Biotechnology Information.

References

Carrión O, Curson ARJ, Kumaresan D, Fu Y, Lang AS, Mercade E, Todd JD (2015) A novel pathway producing dimethylsulphide in bacteria is widespread in soil environments. Nature Communications 6**,** 8.

Curson ARJ, Todd JD, Sullivan MJ, Johnston AWB (2011) Catabolism of dimethylsulphoniopropionate: microorganisms, enzymes and genes. Nature Reviews Microbiology 9, 849-859.

Eyice Ö, Myronova N, Pol A, Carrión O, Todd JD, Smith TJ, Gurman SJ, Cuthbertson A, Mazard S, Mennink-Kersten MASH, Bugg TDH, Andersson KK, Johnston AWB, Op Den Camp HJM, Schäfer H (2018) Bacterial SBP56 identified as a Cu-dependent methanethiol oxidase widely distributed in the biosphere. The ISME Journal, 12**,** 145.

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Stefels J, Dacey JWH, Elzenga JTM (2009) *In vivo* DMSP-biosynthesis measurements using stable-isotope incorporation and proton-transfer-reaction mass spectrometry (PTR-MS). Limnology & Oceanography Methods, 7, 595-611.

6.3 Seasonal sea ice – a new source of bromine during polar night

K. Abrahamsson (SE.GU), A. Dumitrascu, P (SE.GU). Simoes Pereira (SE.GU) and the BGC team (for year-round service)

Objectives

The aim of the project is to study emissions of biologically produced trace gases i.e. halocarbons, which are identified as ozone-depleting, and are hence the subject to present and future regulation under international agreements (e.g., the Montreal Protocol). Although significant effort has been made to generate global budgets of halogenated compounds, the Arctic Ocean has so far been neglected in these models, hindering accurate prediction of the ozone layer over the next decades. Additionally, there is still a wide knowledge gap on the influence of sea ice – atmosphere interactions to these halogenated compounds, especially during polar night. Changes in sea ice distribution, concentrations and age, especially in the Arctic where the extent of multiyear ice has declined substantially compared to seasonal ice, affect the atmospheric composition of halogens. Halogen species involved in the depletion of ozone are associated with new sea ice formation, particularly during polar winter. For instance, during Antarctic winter, estimates of ozone-depleting halogen fluxes from seasonal ice are 100 to 1,000 times than during to summer (Abrahamsson et al., 2018).

During the MOSAiC expedition, we will analyse halocarbons concentrations at the ocean-ice-atmosphere interface during the Arctic winter to further our understanding on the biogeochemical processes that occur during sea ice growth, as well as their impact on Arctic tropospheric chemistry. We will also investigate the role of ice as a reaction surface for chemical conversion processes, and therefore as a source for halogens to the atmosphere. We will estimate the contribution of seasonal sea ice to the load of halocarbons in the troposphere during polar night, which will improve existing uncertainties in global flux models of halocarbons through air-sea-sea ice measurements.

Work at sea

Measurements of halocarbons, (including brominated, iodinated and chlorinated compounds) will be conducted on air, sea ice, snow and seawater in order to estimate their flux, and therefore, the importance of Arctic sea ice as a source for ozone-depleting halogen compounds during winter. Ice cores will be sampled and divided into 10 cm or 5 cm sections and thawed in gas-tight Tedlar^{TM} bags (Granfors et al., 2014). Snow samples will be treated in a similar way. A suite of halocarbon compounds will be quantified where $CHBr_3$, CH_2Br_2, $CHCl_2Br$, $CHClBr_2$, CH_3I, CH_2ClI and CH_2I_2 are of main interest. Samples will be analyzed with a purge-and-trap system (Teledyne) connected to a gas chromatograph with electron capture detector (Thermo). A custom-made purge-and-trap instrument is equipped for semi-automatic air and seawater sample analysis. Air will be continuously drawn through a 100 m long Teflon tube with a diameter of 4 mm with the help of an air pump located down-stream from the sampling loop. The instrument will also be fed with a continuous stream of water from the ship´s surface water inlet. The determination is made with gas chromatograph with electron capture detector (Thermo). Finally, additional seawater will be collected with the CTD/water bottle system.

Preliminary (expected)

- Estimates of the contribution of seasonal sea ice to the fluxes of halocarbons to the Troposphere.
- Minimize the uncertainties in global flux models of halocarbons through air-sea-ice measurements.

Data management

The data will be quality controlled as soon as possible after the expedition. This procedure includes inter-calibration between the two instruments. All data are handled, documented, archived and published following the MOSAiC data policy.

References

Abrahamsson K, Granfors A, Ahnoff M, Cuevas CA, Saiz-Lopez A (2018) Organic bromine compounds produced in sea ice in Anarctic winter. Nature communications. 95291, 1-8.

Granfors A, Ahnoff M, Mills MM, Abrahamsson K (2014) Organic iodine in Antarctic sea ice: a comparison between winter in the Weddell Sea and summer in the Amundsen Sea. Journal of Geophysical Research 119, 2276–2291.

6.4 The sea-ice ocean interface throughout the year: imprint of the melt and freeze cycle reflected in stable isotopes of H_2O ($\delta^{18}O$ and δD)

D. Bauch (DE.GEOMAR), BGC team (for sampling)

Objectives

The aim of the project is a process-oriented understanding of the effect of the melt and freeze cycle on the upper water column and on sea-ice throughout the year in order to better assess the stability of the Arctic Ocean halocline and sea-ice related gas and matter fluxes.

The investigations will use stable oxygen isotope measurements ($\delta^{18}O$) and Deuterium (δD).

Work at sea

We will obtain water samples from the water column for $\delta^{18}O$ analysis and from ice cores for $\delta^{18}O$ and δD analysis. On a regular basis it is planned to take weekly water samples of upper water column from the from ocean city rosette. Weekly sea-ice cores with a resolution of 5 cm within at least two different ice types (overlying ice floe and from newly formed ice and different ice types within the MOSAiC Distributed Network). In addition, it is planned to sample certain special events that might also suspend regular sampling. For the BGC group and this project such special events are: storms, opening of leads, new ice formation, sea-ice formation events, snowfall with negative freeboard and refreezing of meltwater ponds

Preliminary (expected) results

As the Mosaic observatory will drift within the sea-ice of the Transpolar Drift that is largely coupled with the movement of the upper water column we will be able to interpret the observed changes within the water column in direct connection with the observed local processes within the sea-ice and in response to local atmospheric forcing. We are aiming to estimate the importance of winter versus summer processes and the importance of local versus advected signals within the Arctic Ocean halocline.

Data management

Data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).

All data are handled, documented, archived and published following the MOSAiC data policy.

References

Bauch D, Schlosser P, Fairbanks RF (1995) Freshwater balance and the sources of deep and bottom waters in the Arctic Ocean inferred from the distribution of H218O. Progress in Oceanography, 35, 53-80.

Bauch D, Rutgers van der Loeff M, Andersen N, Torres-Valdes S, Bakker K, Abrahamsen EP (2011) Origin of freshwater and polynya water in the Arctic Ocean halocline in summer 2007, Progress in Oceanography, 482-495, doi:10.1016/j.pocean.2011. 1007.1017.

6.5 Tracer oceanographic studies based on neodymium isotopes (ε_{Nd}) and REEs

G. Laukert (DE.GEOMAR, not on board), BGC team (for sampling)

Objectives

Radiogenic neodymium (Nd) isotopes and rare earth elements (REEs) will be used to trace the distribution and mixing of Arctic water masses within the upper water column of the Transpolar Drift System. This will allow to determine contributions of the various Arctic waters and their spatiotemporal variability (Laukert et al., 2017a, b, c; 2019), and to investigate the year-round interaction of the upper water column with the sea-ice and snow cover.

Work at sea

Water samples (10L) will be obtained every 3-4 weeks from: surface, 50 m, 100 m and 200 m.

Preliminary (expected) results

Radiogenic Nd isotopes have been widely applied to trace modern ocean circulation, as well as atmospheric and continental inputs to the global ocean. Their suitability along with REEs to trace ocean circulation and freshwater pathways in the Arctic Ocean was demonstrated by several studies, including Laukert et al. (2017a, b, c; 2019). Seawater Nd isotope distributions within the Transpolar Drift System reflect water mass advection and mixing, while interactions with particles are only found above the shelves. However, Nd isotope signatures on the Siberian shelves are not affected by such interactions (Laukert et al., 2017b), which allows the use of Nd isotopes to trace Siberian freshwater inputs and pathways downstream the Transpolar Drift. Pacific and Atlantic Water can also be traced in the central Arctic Ocean (Paffrath et al., in prep.) and at Fram Strait (Laukert et al., 2017a; Laukert et al., in prep.). Moreover, interactions between sea ice and the water column can change the marine signatures (Laukert et al., 2017c) and thus in addition to atmospheric input can be investigated based on Nd isotopes.

Data management

Data will be provided to the MOSAiC Central Storage and form the basis of publications.

All data are handled, documented, archived and published following the MOSAiC data policy.

References

Laukert G, Makhotin M, Petrova MV, Frank M, Hathorne EC, Bauch D, Böning P, Kassens H (2019) Water mass transformation in the Barents Sea inferred from radiogenic neodymium isotopes, rare earth elements and stable oxygen isotopes. Chemical Geology, 511. pp. 416-430, DOI: 10.1016/j.chemgeo.2018.10.002.

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6.6 Determining air-sea and sea-air fluxes with the naturally occurring radionuclides ^{7}Be and ^{222}Rn

D. Kadko (EDU.FIU), W. Geibert (DE.AWI, not on board), W. Landing (EDU.FSU, not on board), C. Buck (EDU.UGA, not on board), C. Marsay (EDU.UGA), M. Stephens (EDU.FIU) and the BGC team (for sampling)

Objectives

Two projects deal with studies of naturally occurring radionuclides, forming a part of the BGC team efforts.

1) Cosmogenic ^{7}Be as a tracer of atmospheric fluxes of trace elements - The cosmogenic radionuclide ^{7}Be (half-life 53 days) is produced in the atmosphere by cosmic radiation. It is deposited onto the ocean surface via precipitation. Its known half-life and source enable us to quantitatively determine the fluxes of airborne particles that deliver trace elements to the Arctic ocean-ice ecosystem (Kadko et al., 2016). However, no winter data from the Arctic are available so far. Our objective is to combine these data with trace metal data from the continuous time-series of aerosol collection, establishing the first winter time-series of atmospheric trace metal fluxes in the Arctic.

2) ^{222}Rn as a proxy of sea-air gas fluxes - Radon-222 (^{222}Rn, half-life 3.8 days) is a naturally occurring radioactive noble gas that is constantly produced by radium-226 in seawater. The concentration of ^{226}Ra is fairly constant and well known in the ocean, and if no loss of gaseous ^{222}Rn occurs, the two isotopes are in a radioactive equilibrium. This condition can only be reached under a closed sea-ice cover, or below the mixed layer of the ocean. In partial sea-ice cover and in open water, gas exchange with the atmosphere will occur and ^{222}Rn is lost to the atmosphere. As a noble gas, ^{222}Rn does not biologically or chemically interact with other seawater components. Therefore, is reflects the physical component of gas loss. Our objective is to produce a ^{222}Rn dataset that will show the timing and location of gas exchange, in particular at the transition from sea-ice covered to open waters (Rutgers van der Loeff et al., 2014).

Work at sea

1) Cosmogenic ^{7}Be as a tracer of atmospheric fluxes of trace elements - The only way to detect ^{7}Be is via low-level gamma counting soon after sampling, after pre-concentrating it from large volumes of water or ice that range from about one liter (fresh snow) to hundreds of liters of seawater. Therefore, a sea-going gamma detector in a large lead shield, cooled with liquid nitrogen, is installed in a container on-board. Large and/ or very active samples may also be transported back and measured in the home lab.

Sampling will be done (a) in snow (melting several L in buckets, then precipitating ^{7}Be with a stable yield tracer (b) in sea ice (to determine inventories) (c) in large seawater samples from the sea surface (several 100 L, to be processed in the fish lab and through the Ocean City hydrohole by pre-concentration onto iron oxide-coated fiber) and (d) aerosol samples (collected weekly as part of this project).

2) ^{222}Rn as a proxy of sea-air gas fluxes - In order to measure ^{222}Rn continuously, a counter that specifically detects ^{222}Rn (RAD7) will be set up and continuously monitor ^{222}Rn from a flow-through cell for gas exchange, sampling from the ship's intake sea-water supply. While count rates are not far from the instrument background, the continuous record should enable us to trace the degree of gas exchange in various ice conditions.

Preliminary (expected) results

1) Cosmogenic ^{7}Be as a tracer of atmospheric fluxes of trace elements - We expect that the ^{7}Be data will enable us to calculate the rate of deposition of airborne substances onto the sea-ice and follow their flux into the sea-ice and from there into the surface ocean. In close collaboration with the atmosphere and sea-ice teams, this will allow us establish selected trace element budgets for the Artic that include the winter season.

2) ^{222}Rn as a proxy of sea-air gas fluxes. We will produce a continuous record of ^{222}Rn concentrations in Arctic surface water. This dataset will show the timing and location of gas exchange.

Data management

^{7}Be data will be partly produced onboard, but a full evaluation and part of the counting can only be done back in the home laboratory. ^{222}Rn data will be produced onboard. All data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).

References

Kadko D, Galfond B, Landing WM, Shelley RU (2016) Determining the pathways, fate, and flux of atmospherically derived trace elements in the arctic ocean/ice system. Marine Chemistry, 182, 38-50.

Rutgers van der Loeff MM, Cassar N, Nicolaus M, Rabe B, Stimac I (2014) The influence of sea ice cover on air-sea gas exchange estimated with radon-222 profiles. Journal of Geophysical Research: Oceans, 119(5), 2735-2751.

6.7 Biochemical links and annual variation of Arctic ice nucleating entities and marine sugars in the SML of melt ponds and open ocean, sea ice, snow, brine and atmospheric particles

S. Zeppenfeld (DE.TROPOS), M. van Pinxteren (DE.TROPOS, not on board), A. Fong (DE.AWI), M. Dall'Osto (ES.ICM-CSIC), H. Siebert (DE.TROPOS, not on board), T. Santl-Temkiv (DK.AU, not on board), H. Wex (DE.TROPOS, not on board), F. Stratmann (DE.TROPOS, not on board), H. Herrmann (DE.TROPOS, not on board)

Objectives

The upper layer of the ocean, the sea surface microlayer (SML) is the direct interface between the ocean and the atmosphere, and is often enriched in organic matter (van Pinxteren et al., 2012; Engel et al., 2017). In recent studies, the Arctic SML was identified as a likely source of atmospheric ice nucleating particles (INP) being more ice active compared to the corresponding bulk seawater (Wilson et al., 2015). Besides the SML of the marginal ice zone, the SML of aged melt ponds contains a lot of efficient ice nucleating entities (INE) (Zeppenfeld et al., 2019). There are indications that this ice nucleating activity (INA) is caused or supported by the presence of locally produced marine sugars, such as microgels. Recently, correlations between the free glucose concentration and the INA in Arctic water samples under consideration of the microbiological composition were observed (Zeppenfeld et al., 2019). So far, the biochemical links between marine carbohydrates and INE, their sources (e.g. sea ice, brine, snow, melt ponds), their transfer to the atmosphere and their annual variations are unclear. To this end, the SML and the corresponding bulk water from open ocean samples and from melt ponds will be studied on marine carbohydrates, INA and several biological parameters (DNA/RNA/phytoplankton pigments) systematically during MOSAiC for an entire year. Furthermore, we will analyze snow, brine and ice core samples for the identification of potential sources. To study the potential transfer of these marine sugars and INE from the ocean/melt ponds to the atmosphere, ground based aerosol particles will be sampled on board of *Polarstern* during the entire MOSAiC campaign. Additionally, the vertical transfer of marine carbohydrates and INE will be studies using the tethered balloon during PS122/4.

Work at sea/ice floe

The sampling of the SML will be performed with an established glass plate technique, while bulk seawater will be sampled in acid-cleaned polypropylene bottles from a depth of ca. 1 m with a telescopic rod. Furthermore, snow, ice core samples and brine will be collected during the MOSAiC campaign.

On board of *Polarstern*, two low volume aerosol pumps will be used to collect aerosol particles on 0.8µm polycarbonate filters for the later INA and marine sugar analysis. Additionally, aerosol particles and cloud water will be sampled during the tethered balloon operations of PS122/4.

Expected results

From the suggested measurements, we expect high quality information concerning the annual variation, sources, transfer and biochemical links between INE and marine sugars in all Arctic compartments (sea ice, melt ponds, snow, brine, ocean water)

Data management

All data collected during the expedition will be stored in the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)).

All data are handled, documented, archived and published following the MOSAiC data policy.

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7. ECOSYSTEM

A. Fong (DE.AWI), R. Gradinger (NO.UIT), R. Rember (EDU.UAF), N. Hildebrandt (DE.AWI), J. Ren (CN.SIO), P. Snoeijs-Leijonmalm (SE.SU), A. Svenson (SE.SLU), M. Lan (CN.PRIC), J. Creamean (EDU.CSU), S. Torres-Valdes (DE.AWI), J. Grosse (DE.GEOMAR), L. Olsen (NO.NPOLAR), G. Castellanie (DE.AWI), L. Eggers (DE.AWI), R. Campbell (EDU.URI), L. Wischnewski (DE.AWI), C. Hoppe (DE.AWI), F. Schaafsma (NL.WUR), A. Torstensson (S.UU), C. Ashjian (EDU.WHOI), A. Ulfsbo (SE.GU), A. Aguilar-Islas (EDU.UAF), H. Flores (DE.AWI), D. Scholz (DE:AWI), R. Campbell (EDU.URI), Y. Zhuang (CN. SIO), M. Graeve (DE.AWI), C. Gelfmann (EDU.URI), O. Müller (NO.UIB), B. Niehoff (DE.AWI), E. Chamberlain (EDU.UCSD), J. Balmonte (SE.UU), K.-U. Ludwichowski (DE.AWI), P. Alatalo (EDU.WHOI), K. Metfies (DE.AWI), E. Chamberlain (EDU.UCSD), K. Schmidt (UK.UPlymouth), E. Droste (UK.UEA), C. Havermans (DE.AWI, not on board)

Objectives

High-latitude ecosystems that use sea ice as a substrate, habitat, and foraging ground are characterized by strong spatial heterogeneity and pronounced seasonal dynamics that reflect their physico-chemical environment. The coupled interactions between sea ice, biology, and chemistry of the ocean-atmosphere system are, however, generally understudied. As a consequence, biological and ecological impacts on the Arctic climate coupled system are often not represented in regional and global climate representations of the Arctic climate system. However, biological activities drive the transformation of organic matter and elements, and can control the cycling of climate-active gases (i.e. CO_2, CH_4, N_2O, and dimethyl sulfide [DMS]) across atmosphere-ice-ocean interfaces. Therefore, biological activities are an important feedback mechanism in the transformation of key elements and gases in the Arctic climate. With MOSAiC, a more complete understanding of the fluxes of important elements (C, N, O, P, S) between the atmosphere, ice, and ocean systems will be gained through a broad focus on ecosystem processes in the ice and the water column, and linkages between these systems.

Rapid changes to sea ice and upper ocean properties will alter Arctic ecosystem functions, but at present, our knowledge of these alterations is primarily from Arctic shelf regions. We know little about how shifts from a predominantly MYI seascape to seasonally-driven FYI regime in the CAO will affect the cascade of ecological processes associated with sea ice. Moreover, we have few field observations and scant experimental data from the CAO beyond the summer season. Summertime snapshots have already alerted us to major changes in the CAO, and the potential impact thinning ice may have on ecosystem processes, but to better evaluate future changes to the CAO, we require observations and experimentation of natural Arctic microbial and faunal communities over the annual cycle. These types of observations and experiments, geared towards elucidating mechanistic underpinnings of biological processes and interactions, will foster significant advances in our knowledge of CAO ecosystem functions, and how they may change in light of continued global warming.

MOSAiC offers the unique opportunity to study biogeochemistry and ecology in the framework of those processes thought to exert strong controls on Arctic biota and related carbon and nutrient cycles. Critical processes to consider will include sea ice formation, lead dynamics, melt pond formation, ocean mixed layer dynamics, and wind-induced upwelling of nutrients. Improved understanding of the biologically-mediated fluxes of elements and energy between ocean, sea ice, and atmosphere also requires the investigation of underlying ecosystem dynamics in the context of these processes, at temporal and spatial scales not previously resolved.

Biological and biogeochemical processes have spatial heterogeneity due to patchiness of ice structure, microbial communities, and interactions with the upper ocean. Moreover, both the magnitude and direction of biogeochemical fluxes appear to evolve with season and with the advance of ice age from its initial formation to its melt. To characterize the biology and biogeochemistry of the CAO, multiple, spatially distributed measurements will be made within the local domain (<2 km), throughout the annual cycle.

MOSAiC Ecosystem objectives are:

1. Produce an annual mass budget of organic and inorganic carbon and alkalinity in the Central Observatory, including crystallographic measurements of Ikaite in brine channels. This budget will address recent and longstanding questions related to the net air-ice flux of CO_2 caused by sea ice biochemistry in addition to the potential for organic carbon trapping and respiration to CO_2, which can only be quantified over an annual cycle.
2. Produce an annual mass balance and ice-water cycling of macro and micronutrients. This will facilitate an evaluation the progressive concentration of nutrients including iron in sea ice for subsequent supporting of the blooms in the upper water layer. Characterize vertical fluxes of nutrients in combination with nutrient tracer assays to understand recycling pathways by microbes in sea ice, euphotic zone, mixed layer, and deep ocean.
3. Conduct oxygen, nitrate and optical measurements from autonomous sensors. Together these measurements can establish whether the sea ice zone on an annual cycle is a net producer of O_2 (net heterotrophy) or a net producer of CO_2 (net autotrophy), and the nature of their evolution over the annual cycle. In particular, net community productivity will also be coupled with measurements of air-sea gas exchange in the sea ice.
4. Quantify the annual cycle of primary production in sea ice and the upper ocean. The Central Observatory provides an unprecedented opportunity to compare estimates of net community production and net primary production (from e.g. O_2/Ar and ^{14}C) to estimates of particle flux from optical backscatter and beam attenuation measurements or sediment traps that can be periodically deployed and retrieved to obtain both annual net and shorter-term resolution.
5. Determine the strength of particle export via the biological pump, including cycling of DOM. This will help to rectify long-standing methodological discrepancies in quantifying gas fluxes by implementing coincident methodologies and investigating the output in real time to help constrain inherent biases. Mass balance estimates can help to ground truth the methods.
6. Characterize the spatial distribution of sympagic and planktonic biomass (e.g., ice algae, phytoplankton, microbes, micro- and meso-zooplankton) and determine their biodiversity. Quantify the energy flow and elemental (C, N, O, P) and compound-specific (e.g. amino acids, fatty acids) cycles in the ice/ocean ecosystem. Special focus will be on the energy flow and the elemental and compound-specific cycles within the sea ice and pelagic communities, and the linkages between the two communities through the quantification of important biological rate processes. Important processes include primary production (new and regenerated), microbial respiration and remineralization, micro-zooplankton feeding and growth, and meso-zooplankton feeding, respiration, growth, and reproduction.

7. Determine standing stocks and distributions of microorganisms and animals in relation to physical conditions (ice, stratification, water masses, etc.) to evaluate the physical-biological interactions that impact production, pelagic retention and vertical export.
8. Determine nutrient fluxes, organismal abundance and biomass of important components of the ecosystem (e.g. ice algae, phytoplankton, zooplankton). Relate these properties to behavioral (e.g. vertical depth preferences and diel or ontogenic vertical migration) and life history (e.g. reproductive timing and overwintering strategies) patterns.

Work at sea

Ship-based and on-floe observations and activities will be conducted to support these objectives. Ecological properties will be mainly derived from discrete physical sampling of the Arctic environment (air, snow, ice, and water). However, we will also supplement discrete measurements with [semi]-autonomous measurement packages, which will provide higher temporal resolution of key properties from distinct positions in the Central Observatory. At the broadest spatial scale, we will have a small number of sensor packages attached to ice and hydrographic buoy systems, which will provide basic chemical and physical data at the atmosphere-ice-water interface. Additionally, we will perform a suite of experiments throughout the annual cycle to augment observations. Experiments cover a broad range of topics, collectively aim to elucidate mechanistic understanding of biologically-catalyzed flows of organic matter, elements, and energy through the Arctic climate system. Together, these measurements and experiments will provide inventories of biological components, fluxes of energy, carbon, and material through the food web, and information about how ecological processes change in response to the physical dynamics of the Arctic environment.

A time-series of ecological, biogeochemical, and biological properties and processes will be built from a coordinated effort to capture a suite of measurements once per week from all components of the Arctic climate system. Once per week, we will conduct cooperative sampling with teams ICE and BGC to measure changes in biological components with respect to the physical and geochemical properties of snow and ice. Our most basic approach will be to establish two coring regions for repeat visits and coring activities for the year-long campaign. Given the region of interest, we aim to track changes in both MYI and FYI. While there are finer delineations of types of MYI and FYI within the CAO, the primary time-series will be generalized to capture differences between FYI and MYI.

The Central Floe Observatory within the direct vicinity of *Polarstern* will be a light-polluted area. Artificial light has strong effects on biological activities from single-celled organisms to fish. Therefore, most ecological measurements from snow and sea ice will be conducted in a dark remote site located ~1-2 km from *Polarstern*. Upon initial surveying of the floe, we will attempt to remain as close to *Polarstern* as possible, but we will implement precautions to prevent sampling within an artificially light polluted area to reduce light impacts on the evolution of biological properties and processes during the dark period. We also will use red-filtered light during our field collections and sample handling to reduce the effect of white light during the polar night.

Within the dark remote region, to avoid disruption of nearby areas with repeat visits, each FYI and MYI time-series coring site will be 500 x 500 m. Each coring site will be further divided into 10 x 10 m plots. Within each 10 x 10 m plot, we will conduct a weekly sampling of co-located physical, geochemical, and ecological properties. Snow sampling of type C will occur first upon arrival at each core plot. Following snow sampling, trace metal clean sampling for micronutrients in snow, ice, and direct-under ice water will commence. In parallel, the main coring activities for the suite of time-series properties coordinated by each team will commence. This ensures that comprehensive information on snow and ice properties are derived from the same coring site for a specific time point in the time-series. Additionally, it allows us to link our measurements together across space and time. In addition to these ice coring plots, the Central Observatory and near–field area will also support clone sites. Clone sites will be used for higher resolution sampling of some snow and ice properties, for monitoring the evolution of melt ponds, and in some cases, for conducting small spatial variability surveys. In addition to coring, we will also partner with the optics team to conduct visual surveys and sampling of melt ponds and leads. Ecological properties from melt pond waters and waters immediately exposed after the opening of a lead will provide further insight into how these features within MYI and FYI change over the seasonal cycle, and influence flux measurements across the atmosphere-ice-ocean interface.

Other activities on ice will include the deployment of visual and acoustic camera systems, installation of a biogeochemical sensor package, deployment of ice-tethered sediment traps, deployment of an assortment of underwater nets for small animal capture, and deployment of incubation bottle arrays. These activities require setting out instruments and allowing measurements and/or collections to occur over periods of hours to weeks. Camera systems will be pre-programmed and deployed for months-long durations. There will be several acoustic camera systems (AZFPs) distributed across the Central Observatory. AZFPs will record layers of organisms ranging in size from millimeters to centimeters. These instruments also will record diel migrations of small organisms. A HD video camera system will be deployed at 500 m depth within the Central Observatory to monitor the presence of macrofauna in the mesopelagic. Video recordings will be pre-programmed to occur for 10-min periods every hour of every day. General weekly maintenance checks and data backups are planned for these camera systems. We will also cooperate with team ICE to conduct under-ice ROV net sampling and video recording. Visual inspections of under-ice topography and associated flora and fauna will be possible using the ROV. We will collect discrete samples of animals and flora from the ROV, which will be complemented by its suite of sensor measurements (i.e. light spectra, fluorescence, etc.).

An under-ice biogeochemical sensor package supporting 6 different sensors will be installed at the FYI dark remote site, with weekly manual downloads of data, and quarterly maintenance checks. These sensors measure pCO_2, nitrate concentrations, fluorescence, particle backscatter, dissolved oxygen, and T/S. These data will provide higher temporal resolution mapping of direct under-ice properties relative to coring activities and water column sampling activities at *Polarstern*. Discrete samples will be collected and analyzed from the FYI site for inter-comparison with sensor data streams.

Several different types of ice-tethered sediment trap arrays will be deployed throughout the year. There will be a large McLane 21-cup sediment trap deployed at 50 m below the ice for the duration of the campaign. The McLane trap will collect an integrated particle flux sample every 3-4 weeks for 12 months. Additionally, there will be a HydroBios 6-cup sediment trap deployed at 20 m, which will collect an integrated particle flux sample every 2-4 weeks. We will recover and redeploy the HydroBios trap array every 2-3 months. Lastly, we will use KC Denmark PIT-style traps to collect particles at 3 depth horizons in the upper 100 m of the water column on time scales of 24-72 hrs. Short-term trap arrays will be deployed near ridged and level sea ice. When possible, short-term traps will also be deployed near the FYI coring site. Sediment trap material will be analyzed for POC/PON, PP, BSi, chl a, IP25, and biomarker pigments. When there is a sufficient amount of material, other properties will also be analyzed from sediment trap material.

An assortment of small mesh size nets will be deployed at the Central Observatory to capture small animals, specifically fish. A scientific assessment of potential CAO fishery stocks will be conducted during MOSAiC, and these net captures will aid in the validation of acoustic and visual camera data streams, and provide material for compound-specific isotope analyses, trophic interaction studies.

On PS122/4 - PS122/6, bottle incubation arrays will be deployed in the Central Observatory. Bottles will contain tracers used to measure the rates of C- and N-compound assimilation by microorganisms. Under-ice incubation arrays are better proxies for mimicking the temperature and light fields natural communities of microorganisms experience, so in combination with our laboratory-based incubations, these measurements will provide information about *in-situ* carbon and nitrogen assimilation rates (i.e. primary productivity and nitrate uptake rates).

Discrete water column sampling will also be conducted to complement snow and ice property measurements. Using samples collected from Niskin bottles mounted to rosette packages, individually deployed bottles, or pumps, we will collect water to be analyzed for a suite of biogeochemical and ecological properties. Full depth water column sampling will occur once per week throughout the duration of the campaign. Additionally, 5-6 shallower casts (i.e. max to 1,000 m) will be used to collect water for additional core measurement sampling and to support experimental activities. A core set of properties and processes will be measured from multiple depth horizons in the water column and sea ice (see Table 7.1). The sampling of water column ecological properties in MOSAiC follows protocols of international hydrographic programmes, which routinely sample geochemical and biological properties. The once-per-week sampling of the full complement of water column properties is a joint effort between teams OCEAN, BGC, and ECO, thereby ensuring temporally co-located measurements of the ocean.

We will also conduct vertical net tows using the multinet midi, LOKI, and an assortment of ring nets with different mesh sizes. Net tows will collect animals that will be sorted to assess species diversity, abundance and biomass. Some animals will also be used for egg production rate measurements, and grazing rate experiments. These components of the fieldwork are integral to building inventories of elemental and energy fluxes through the Arctic food web, and discerning the role these organisms play in feedbacks between the ocean and atmosphere. In addition to discrete sampling of animals, we will also utilize visual and acoustic camera systems to map the horizontal and vertical distribution of animals associated with ice, and their daily migrations in the vertical water column. Together, the suite of temporally co-located biogeochemical and ecological observations and measurements will provide a time-series of Arctic ecosystem functions and processes in the context of the dynamic physical environment.

Lastly, these ship-based measurements will play a critical role in providing common calibration references for a large suite of autonomous sensors distributed in and around the Central Observatory, and for building proxies (e.g., calibration of nitrate sensors, chlorophyll fluorescence to chlorophyll concentration, optical backscatter and beam attenuation to POC, optical properties to phytoplankton community composition, acoustic measurements for zooplankton composition). Careful laboratory calibration and cross calibration will help place the entire sensor network into a common reference, facilitating quantitative analyses that employ multiple, coordinated platforms. The proxy relationships allow leveraging of the extensive, but spatially limited, ship-based sampling onto the much more numerous, distributed measurements provided by the autonomous sensor network.

Tab 7.1: Planned Ecosystem-coordinated variables for MOSAiC time-series at *Polarstern* and Central Observatory. Distributed Network sampling not listed, but will be a less frequent subset of specific key variables for sensor calibration and measurements (1x month). Sampling and onboard analyses will be adjusted accordingly.

Ecosystem Key Variables	**Environments & Resolution**	**Method**	**Ice camp (CO) & *Polarstern***
Chemistry – concentrations, quality, stoichiometry, fluxes, budgets			
Macronutrients (nitrate, nitrite, ammonium, phosphate, silicic acid, DON, DOP)	Water: 10 depth horizons Sea ice: every 5 cm	SEAL AA3 Auto-analyzer Onboard *Polarstern* TN/TP (frozen, onshore only)	1x per week
Dissolved Oxygen (DO)	Water: 6 – 10 depth horizons Sea ice: none (sensor-based)	Winkler titration	1x per week
Carbonate chemistry (TA, DIC)	Water: 10 depth horizons Se ice: need to determine best method(s)	Coulometry & VINDTA	1x per week
DOC/DOM concentration and characterization; CDOM	Water: 6 - 10 depth horizons Sea ice: 0-5, 5-10, then every 10 cm	Solid phase extraction (onboard) FT-ICR-MS	1x per week
Oceanic particle size spectra and distributions;	Water column only; Sensor mounted on CTD-rosette package	Optical - Underwater Vision Profiler (UVP): *Polarstern* rosette only	1x per week
Sinking Particulate carbon, nitrogen phosphorus, and biogenic silica (POC, PON, POP, BSi)	Single Depth horizon for HydroBios 6-cup trap, deployment duration 4-8 weeks; PIT traps, depth horizons tbd, Deployment time 1-3 days	*In-situ* traps C/N elemental analyzer Spectrophotometry Wet-alkaline method	HydroBios – 1x month PITs – 1x month PS122/1; 0x PS122/2, 2x month PS122/3, 1x per week PS122/4 - PS122/6
Diversity, Biomass, Abundance, Activity – genes, species, populations, communities			
Chlorophyll a	6 depth horizons; total onto GF/F filter 1 horizon, size-fractionated	Fluorometry Onboard *Polarstern*	1x per week Daily
Pigment Biomarkers	6 depth horizons; total onto GF/F filter	High Performance Liquid Chromatography (HPLC)	1x per week
Prokaryotes (Bacteria and Archaea)	8 depth horiozons 8 depth horizons	Flow cytometry (FCM) DNA/RNA sequencing Eco-Omics suite	1x per week

Diversity, Biomass, Abundance, Activity – genes, species, populations, communities			
Eukaryotic microbes (protists)	6 depth horizons	Flow cytometry (FCM) DNA/RNA sequencing Eco-Omics suite Light microscopy	1x per week
Meiofauna / Microzooplankton	Water: 5 horizons Ice: yes	Water sampling DNA sequencing ROV Net	1x per week
Meso/Macrozooplankton Fish (polar cod)	5 horizons Multinet: [2000-1000-500-200-50-0 m] Ring nets: integrated 0-100m and 0-1000m	Multinet Midi LOKI ROV Net	1x per week

Processes & Rates – When? How fast? How efficient?			
Primary productivity (NPP) Dark carbon fixation	Water: 5 depth horizons Ice: 1 horizon, 2 ice types [bottom only]	14C-bicarbonate tracer 24hr incubation	1x per week
Primary productivity (NPP) Dark carbon fixation	Water: 3 depth horizons Ice: 1-2 depth horizons [bottom]	13C-bicarbonate tracer 24 – 48 hr incubation	1x per week
Photophysiology of autotrophs	Water: 1-3 depth horizons Ice: 1 horizon [bottom]	Fast repetition rate fluorometry (FRRF) PI curves	1x per week 1x month
Net community production (NCP)	Seawater intake ~10 m depth horizon	MIMS; O2/Ar measurements	Continuous
Community respiration L and D incubations	Water: 6-10 depth horizons Ice: tbd	Optodes (Presens); 6-12 hr incubations	1x per week
Respiration, grazing, reproductive rates/indices	Water: tbd Ice: none	Grazing rates, reproductive indices	1x per week or 2x month
Bacterial productivity (BP)	Water: 10 depth horizons Ice: 5 horizons	3H-leucine tracer 12-18 hr incubation	1x per week
Nitrogen assimilation rates measurements:	Water: 3 depth horizons (alternating)	15N-Nxx tracer - nitrate, ammonium, N2, urea, AAs	1x per week

Preliminary (expected) results

The suite of observations and measurements will produce a step-fold increase in the number of ecological measurements from the CAO, and some will be the first measurements of such properties from polar night in the CAO. The key output will be the comprehensive time-series of complementary measurements across physical, chemical, and biological properties of the atmosphere, sea ice, and ocean. We will produce the first year-long time-series of primary productivity, bacterial production, net community production, and community respiration rates from the CAO. In combination with our measurements of the Arctic carbonate system, these observations will provide insight into the buffering capacity of the Arctic Ocean, and how reductions in MYI, sea ice, and thinning will alter future predictions of the CAO's carbon cycle. We will also have measures of algal fitness and photophysiology of natural communities during low light periods. In conjunction with these measures, we will have coincident measurements of incoming irradiance and under-ice light properties to nest rate measurements into environmental context. Additionally, we will produce the first ever observations of zooplankton and macrofauna species diversity, abundance, biomass, and inter-species interaction data from polar night in the CAO. We will also provide key information about the nutrient and DOM pre-conditioning of sea ice and oceanic waters leading into the growing season. This is an important, yet missing, component of our collective understanding of observed processes in Arctic summer. For the first time, we will have a time-resolved inventory of macronutrient and organic matter pools from sea ice and upper ocean waters, which will give us important information about the chemical settings before spring/summer algal growth begins. This will improve our understanding of how nutrient and organic matter inventories change over time and by what biological processes. This information coincides with nearly a full year of nitrogen and carbon compound assimilation rate measurements, including the use of urea and amino acids as substrates, which are suspected to be important energy sources for microbes. We will also capture the transition in biological activities from winter to spring, and measure ecosystem-wide responses to ice formation and melt onset. We will produce a number of new observations for classical and "modern" biogeochemical box models, which will further improve parameterizations of biological components and processes in regional and global climate models. Moreover, we will provide some of the first measurements from the CAO of phytoplankton and sea ice algal production phenology. This information is critical for understanding how physical changes in sea ice and upper ocean waters will affect the base of the food web and trophic cascades.

MOSAiC provides a unique opportunity for us to increase both the number and kinds of ecological and biological measurements from the CAO, specifically within the concept of coupled systems. We envision producing a number of synthesis products from our observational and experimental work, but also a suite of cross-cutting products that utilize a wide range of data from MOSAiC.

Data management

Meta data and sample registry data produced onboard will be regularly uploaded into the MOSAiC Central Storage (MCS) and backed up on physical hard drives associated with individual instruments. Primary data generated onboard will also be uploaded to the MSC. Electronic copies of physical laboratory and field log books will also be stored on the MSC. During the field campaign, there will be a limited number of primary data streams produced, but many sample streams will be produced. More than 80 % of samples from MOSAiC Ecosystem work will be processed and analyzed at onshore facilities. We anticipate beginning lab analyses in parallel to the field campaign, but this is contingent on the safe transport of samples from *Polarstern* to resupply vessels and shore. A prioritization plan of sample processing will be implemented to enhance the output of time-sensitive data, though at some stage, all samples will be processed, so that time-series analyses can occur. Data generated from the Eco team core measurements are owned by the Eco team consortium, as every endorsed project contributes to the generation of these data. Individual PIs own project-specific data, but are obligated to upload and store these data to the MCS. All meta and primary, and some processed data will be stored on the MCS for the embargo period. The MOSAiC data policy applies to all data generated from MOSAiC Ecosystem team. Therefore, all data will be available for use by the MOSAiC Consortium during the embargo period as it becomes available, and eventually all data will be publicly available in PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)), and respective databases for unique data sets (i.e. sequence data).

All data are handled, documented, archived and published following the MOSAiC data policy.

References

NONE

8. REMOTE SENSING

Gunnar Spreen (DE.UNI-Bremen), Roland Kwok (GOV.JPL)

Objectives

Satellite remote sensing is the ideal tool to obtain Arctic-wide and long-term observation of the sea ice cover, ocean, and the atmosphere above. Remote sensing datasets can be used to extend the local MOSAiC observations to a larger scale and set them in context with preceding environmental conditions, like the history of the ice floes MOSAiC will be established on. MOSAiC provides ideal conditions for validation of satellite remote sensing observations: (a) it is a rare case to observe the complete seasonal cycle. Especially winter observations from the central Arctic are basically absent. (b) The MOSAiC concept to not only have one central measurement site but a distributed grid of measurements that cover the typical satellite footprint scales make meaningful comparisons feasible. (c) Furthermore, the combined MOSAiC airborne campaigns will allow to bridge the gap between *in-situ* and satellite observations.

Satellite remote sensing data will contribute to MOSAiC under two different aspects:

First, remote sensing for scientific applications like (i) ground truthing of existing satellite data with *in-situ* observations, (ii) collection of *in-situ* data to develop new or improve existing remote sensing methods (Section 8.1), and (iii) collection of a comprehensive satellite remote sensing dataset covering the whole drift and comprising all available satellite sensors from different space agencies for data interpretation after the experiment. Second, remote sensing will support operations in the field like navigation and selection of measurement sites: (i) provide sea ice concentration and type, (ii) higher resolution SAR imagery, (iii) weather data, and (iv) high resolution visual images (Section 8.2).

The constellation of MOSAiC observations, and associated aerial measurements, will offer a comprehensive spatial perspective on many key parameters on the scale of satellite footprints and along measurement ground tracks. The full annual cycle coverage also offers a particularly unique opportunity for ground validation and understanding of numerous satellite measurements in all seasons. Specific measurements that can be useful in this regard include sea ice spatial distribution and thickness, snow properties, melt pond fraction, deformation scales, atmospheric meteorological parameters, and ocean surface properties. In addition to the benefit of MOSAiC data for satellite validation, satellite observations themselves offer the ability to generalize and upscale the detailed MOSAiC observations to pan-Arctic scales and/or to interpret them within a pan-Arctic context. High resolution satellite observations will also help to upscale from the floe scale ground measurements to the grid scale of regional climate models.

8.1 On-ice and *Polarstern* remote sensing measurements

G. Spreen (DE.UNI-Bremen), E. Cardellach (ES.ICM-CSIC, not on board), T. Casal (INT.ESA, not on board), O. Demir (EDU.OSU), B. Downs (EDU.OSU), C. R. Duguay (CA.UWaterloo, not on board), F. Fohlmeister (DE.DLR, not on board), S. Fons (EDU.UMD), C. Gabarró (ES.ICM-CSIC, not on board), C. Haas (DE.AWI), S. Hendricks (DE.AWI), M. Huntemann (DE.AWI/ DE.UNI-Bremen) , P. Hwang (UK.UHuddersfield), L. Istomina (DE.AWI), J. Johnson (EDU.OSU), L. Kaleschke (DE.AWI), M. König (DE.CAU), T. Krumpen (DE.AWI), N. Kurtz (GOV.NASA), R. Lei (CN.PRIC), R. Naderpour (CH.WSL), V. Nandan (CA.UCALGARY), J. Martinez (ES.ICM-CSIC), N. Oppelt (DE.CAU), R. Ricker (DE.AWI), S. Savstrup Kristensen (DK.DTU, not on board), R. Scharien (CA.UVICTORIA), M. Schwank (CH.WSL, not on board), M. Semmling (DE.GFZ, not on board), J. Stroeve (COM.UCL), W. Wan (CN.PU., not on board), M. Webster (GOV.NASA), J. Yackel (CA.UCALGARY, not on board), R. Tonboe (DK.DMI)

Objectives

One scientific goal of MOSAiC for remote sensing is the ground validation of satellite products and to develop new method to retrieve improved sea ice parameters from satellites. The on-ice remote sensing measurements are part of the ICE team and are integrated in the ICE weekly schedule (see Section 4). Research questions are:

- How well do satellite algorithms perform in the Central Arctic for parameters such as sea ice thickness distribution, snow depth, ice type, floe sizes, ice concentration, and ice drift and deformation?
- Can co-located ground-based sea ice/snow and microwave measurements help to develop improved satellite retrieval methods for ice area, thickness, type, and snow depth?
- Can detailed ground-based measurements of inherent optical properties (IOPs) of melt ponds and sea water help to improve satellite-based assessment of melt pond properties (extend, depth, biology) and the optical properties of open water in the Arctic?

Most observed changes of the Arctic climate system are based on results from satellite remote sensing, which is one of the most important and reliable tools for Arctic monitoring. However, most satellites do not directly measure the geophysical parameters that are needed for research and monitoring. Sea ice concentrations, for example, are typically derived from passive microwave brightness temperatures or high-resolution radar images. Both methods make use of the characteristic difference between surface properties of open water and sea ice, which can be complicated by a variety of seasonal and conditional factors. Sea ice thickness is derived from microwave brightness temperature (thin ice) or from altimeters. Altimeters measure the ice or snow freeboard, which is then converted to ice thickness based on critical assumptions on snow depth and snow/ice densities. Continuous development of methods and algorithms to analyze satellite measurements is necessary to improve observational capabilities, reduce uncertainties, and ensure consistency of satellite data sets.

Work at sea

Several remote sensing (RS) instruments will be operated on the ice and from the ship in the Central Observatory. Table 8.1 gives an overview about all instruments and the responsible PIs.

Measurements will be used for satellite remote sensing validation and the development of new remote sensing methods. There will be reserved undisturbed snow/sea ice areas “Remote Sensing Sites” where most of the remote sensing work is consolidated (see map of floe layout in Section 2). All measurements will be taken either quasi-continuously or with at least weekly repetition to fully cover the complete seasonal cycle from winter, spring, to summer.

The measurements listed in Table 8.1 are combined with detailed measurements of the snow and sea ice at the remote sensing validation site (e.g., thickness, densities, SSA, temperature, salinity, ice stratigraphy). The mobile ARIEL radiometer and Ku/Ka-band radar systems will be towed along regular transects together with ice and snow thickness measurements (see “Transects” task in Section 4). Specific snow and ice measurements will also be regularly taken for the evaluation of the ICESat-2 laser altimeter and satellite microwave radiometers and Synthetic Aperture Radars (SAR). Regular detailed measurements of melt pond parameters such as extent, depth, IOPs (inherent optical properties) will help to develop optical satellite retrieval of melt pond properties.

Coordination of satellite acquisitions with in-situ measurements

Coordinated acquisitions of high-resolution satellite scenes are planed (e.g., polarimetric multi-frequency SAR observations from different satellites plus high-res visual data). For such events additional planning and implementation in the field in agreement with the teams on land, who do the ordering, is needed.

Important supplementary ground measurements for the remote sensing programme (mainly from ICE team)

- Meteorological data acquired on and around the ship
- Helicopter: laser scanning, thermal and visual imaging, and EM ice thickness (also from airplanes whenever involved in the measurements), covering as large as possible parts of satellite scenes
- Snow: snow height, density, grain size, moisture, salinity, presence of special structures (snow crust, superimposed ice)
- Sea Ice: sea ice topography from laser scanning and characterization of ice surface (smooth, rough on mm-, cm-scale etc.), ice coring for measuring thickness, density & salinity, thick sections of air bubble occurrence and bottom layer of the ice core
- Thin ice (pancakes, nilas...) on leads: salinity, thickness, ice inclusions, presence of frost flowers, photography providing an overview of the lead and adjacent ice
- Open water leads (situation around time of satellite data acquisition: wind and/or water surface roughness, evolution of frazil/grease ice, Langmuir circulation, ice herding
- Ice dynamics: position data from all buoys of the Distributed Network

Tab 8.1: List of remote sensing instruments in the Central Observatory

Instrument	*Details*	*PI*	*Institution*
On the ice			
Ku/Ka-band radar	Radar for snow and sea ice thickness investigation (altimetry), Manufacturer: ProSensing Inc.	J. Stroeve	UCL/U Manitoba
L, C, X, Ku-band Scatterometer	Three instruments (4 frequencies), Manufacturer: ProSensing, Inc.	Yackel/Scharien/ Duguay	U Calgary/U. Victoria/U. Waterloo
MW radiometer UWBRAD	Ultra-wideband 0.5 – 2 GHz radiometer for snow and sea ice (P to L-band)	J. Johnson	Ohio State University
MW Radiometer ELBARA	1.4 GHz (L-band)	Schwank/ Kaleschke/Casal	WSL/AWI/ESA
MW Radiometer HUTRAD	7, 11, 19, 37 GHz (C, X, K, Ka-band)	Lahtinen/Spreen/ Casal	FMI/U Bremen/ ESA
MW Radiometer SSMI	19, 37, 89 GHz (K, Ka, W-band)	J. Stroeve	UCL/U Manitoba
MW Radiometer Balamis ARIEL	1.4 GHz (L-band)	C. Gabarro	CSIC
GNSS-R	reflected GNSS signals from snow/ice (ice thickness altimetry and scatterometry)	Cardellach/ Martin-Neira	ICE-CSIC/ESA
Infrared Camera	Surface temperature	G. Spreen	U Bremen
Video Camera	Visual overview of RS site	G. Spreen	U Bremen
Hyperspectral Camera	Snow and melt pond spectra 400-1000 nm	G. Spreen	U Bremen
On Polarstern			
GNSS-R	reflected GNSS signals from snow/ice	Wan/Xie	Peking U.
GNSS-R	reflected GNSS signals from snow/ice and GNSS for atmospheric water vapor	M. Semmling	GFZ
GNSS Ionosphere	Ionospheric scintillations by GNSS phase and amplitude measurements	F. Fohlmeister	DLR
MW Radiometer EMIRAD2	1.4 GHz (L-band)	Savstrup Kristensen/ Kaleschke/Casal	DTU/AWI/ESA

Remote Sensing Site Concept

To avoid snow accumulation and maintain a natural snow cover at the RS measurement sites the on-ice RS instruments have to be moved on a regular schedule (minimum every 2-3 weeks, depending on flex time availability). This also will allow to monitor different snow/ice situations and guarantee that the RS instruments are moveable at all times. The RS instruments are best operated with electrical power from the MOSAiC power line. Therefore, the main RS site will be located at a power and network hub, where also a hut for shelter is available. A second RS site will be located on the young/first-year ice after it grew thick enough to allow instrument deployment (>50 cm) without electrical power. Potential a third site will be located on a different ice type in the Central Observatory (if present).

The following setup will be implemented:

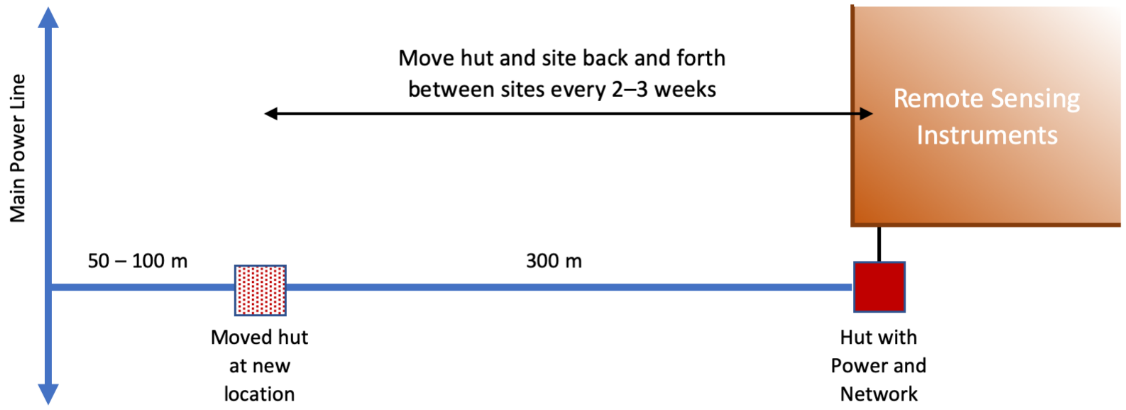


Fig. 8.1: Overview of the remote sensing site setup and how it is moved along the power line

- All RS instruments look at the same snow/ice (as far as possible)
- Scatterometers do azimuth scanning and thus cover a larger area
- The snow surface topography will regularly (weekly) be scanned by laser scanner
- Sea ice thickness will be monitored by thermistor chains
- Detailed snow measurements (parent snow pit) will be conducted close by for a similar snow and ice thickness situation.
- Ice cores (temperature, salinity, density, stratigraphy) will be taken close by. Some distance to the RS site has to be maintained to avoid flooding in case of negative freeboard.

Schematic layout of RS site:

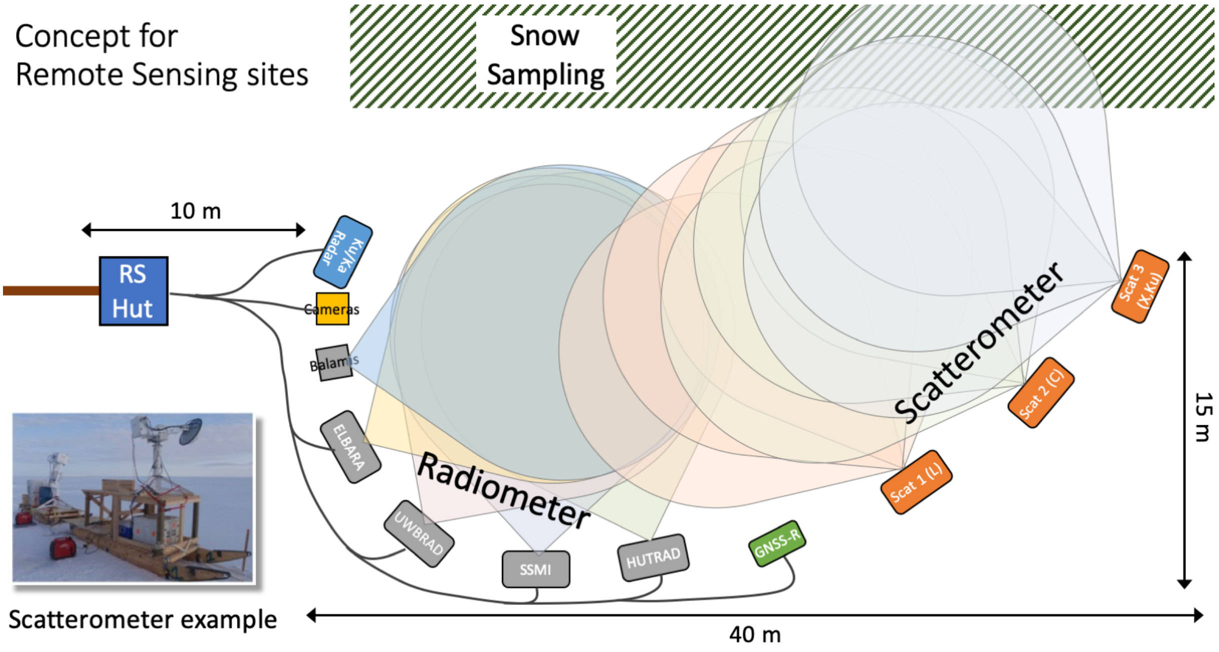


Fig. 8.2: Schematic layout of the remote sensing site. The actual layout will depend on the conditions on the floe.

Polarstern installations

The instruments listed under “On *Polarstern*” in Table 8.1 will be installed on *Polarstern*’s P-deck looking at the ice on port side, i.e., towards the main floe of the Central Observatory (exception: “GNSS Ionosphere” is looking upward only). These installations have the advantage of already measuring from day 1 and already during the transit (outside the EEZ) and that they can also be operated during bad weather periods or ice break-up, when the other on-ice RS instrumentations might get pulled in. A disadvantage likely will be that the snow and ice conditions next to *Polarstern* will not be very typical anymore after a while (snow accumulation, Skidoo and PistenBully operations etc.).

Preliminary (expected) results

All RS instrument will provide a time series of the seasonal development of their measured parameters, i.e., microwave brightness temperature and backscatter at different frequencies, reflected GNSS signals, infrared temperatures and visual images. Their variability and changes will depend on the atmospheric conditions, e.g., temperature and snow accumulation. The combination of on-ice remote sensing measurements together with the comprehensive snow and ice measurements will allow to improve microwave emission and scattering models of snow and ice, which in turn will lead to improved satellite remote sensing datasets.

Data management

All final data of all on-ice remote sensing instruments will be stored at the MOSAiC Central Storage (MCS) and at PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) after post-processing and careful quality checks. Storage and release of data follow the MOSAiC data policy.

All data are handled, documented, archived and published following the MOSAiC data policy.

8.2 Satellite remote sensing products

G. Spreen (DE.UNI-Bremen), R. Kwok (GOV.JPL, not on board), T. Krumpen (DE.AWI), S. Singha (DE.DLR), T. Eltoft (NO.UIT), O. Folomeev (RU.AARI, not on board), S. Hendricks (DE.AWI), S. Howell (CA.ECCC, not on board), K. Hyub-cheol (KR.KOPRI, not on board), L. Kaleschke (DE.AWI), A. Korosov (NO.NERSC, not on board), A. Lifermann (FR.CNES, not on board), G. Macelloni (IT.CNR, not on board), N. Oppelt (DE.CAU), J.-W. Park (KR.KOPRI, not on board), J. Pelon (FR.UPMC, not on board), T. Toyota (JP.HOKKAIDO), S. Willmes (DE.UNITRIER, not on board)

Objectives

First, collection of a comprehensive satellite remote sensing dataset covering the whole drift and comprising all available satellite sensors from different space agencies for data interpretation after the experiment. Second, remote sensing will support operations in the field like navigation and selection of measurement sites: (i) provide sea ice concentration and type, (ii) higher resolution SAR imagery, (iii) weather data, and (iv) high resolution visual images.

Work at sea

A large number of satellite datasets will be collected during MOSAiC. A list of all datasets that will be available in the MOSAiC Central Storage (MCS) after the campaign is Given in Table 8.3. Most of them are freely available and will be converted to a consistent data format (Netcdf) and cut out for the larger MOSAiC region (Central Arctic). However, some of them need special ordering and/or are not freely available (marked green in the first column). For these PIs were identified and for all SAR datasets acquisitions are coordinated by Suman Singha (DLR). The WMO Polar Space Task group supports MOSAiC and a comprehensive collection of SAR data will be available. Experiments with multi-sensor acquisitions together with *in-situ* and airborne measurements are planed (see also Section 8.1).

For navigation and experiment planning purposes a subset of datasets that are of more general interest were identified (Table 8.2). These datasets will be available in near real-time and have a small file size quicklook product that can be transferred to *Polarstern*. Most of these will be available in the *Polarstern* map server for general use by crew and scientists.

Tab 8.2: Satellite data available on *Polarstern*

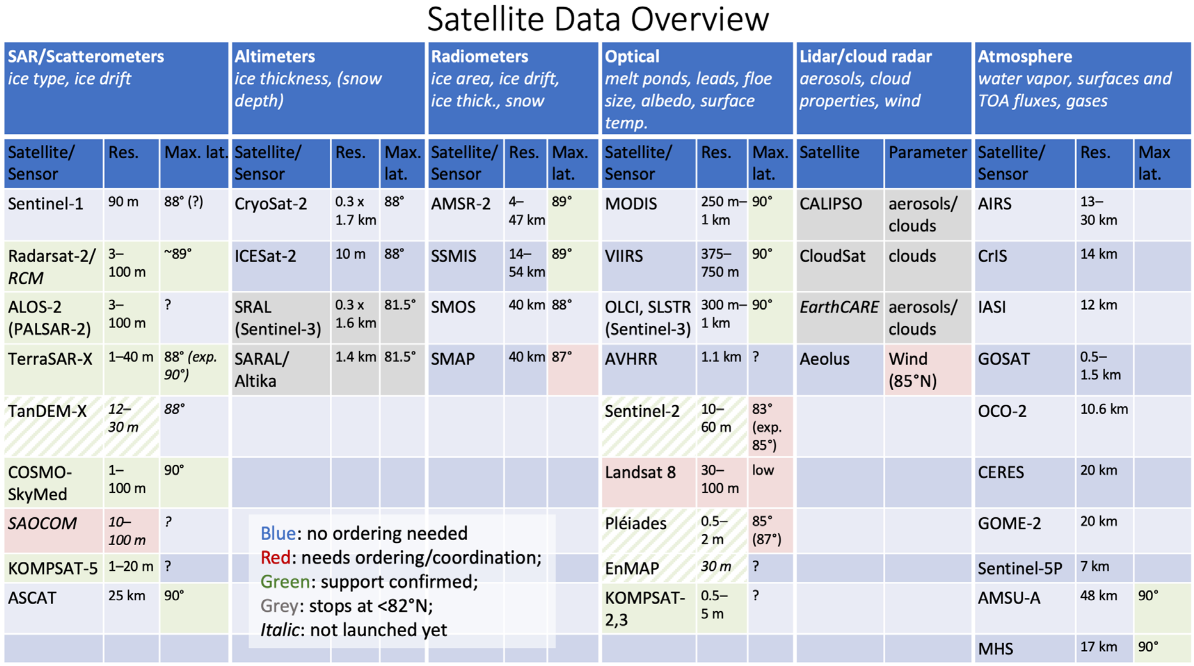
Satellite/Sensor	Type	Parameter	Resolution	Max. latitude	Provider/ Contact
Sentinel-1	SAR	Backscatter	50 – 250 m	88°	Drift and Noise
Sentinel-1	SAR	Ice drift		88°	ECCC/Steve Howell
Radarsat Constellation Mission	*SAR*	*Backscatter*			*ECCC/Steve Howell*

Satellite/Sensor	**Type**	**Parameter**	**Resolution**	**Max. latitude**	**Provider/ Contact**
Radarsat Constellation Mission	*SAR*	*Ice drift*			*ECCC/Steve Howell*
TerraSAR-X	SAR	Backscatter	1 – 20 m	88°	DLR/Suman Singha
TerraSAR-X	SAR	Ice type		88°	DLR/Suman Singha
Cosmo-SkyMED	SAR	Backscatter		90°	ASI&CNR/ Giovanni Macelloni
AVHRR	Optical	Reflectance	250 m – 1 km	90°	*Polarstern*
MODIS	Optical	Reflectance	1.1 km		*Polarstern*
AMSR2	MW Radiometer	Ice Concentration	5 km	89°	Drift and Noise
AMSR2+SSMIS + ASCAT	MW Radiometer & Scatterometer	Ice Drift	62.5 km	89°	OSISAF
AMSR+MODIS	MW Radiometer & Optical	Ice Concentration	1 km	90°	U Bremen/ Gunnar Spreen
SAR and other sources	SAR, Optical, MW radiometer	Ice Charts		90°	AARI
CryoSat-2	Altimeter	Ice Thickness		88°	AWI/Stefan Hendricks
*green datasets are already implemented on *Polarstern*					

Preliminary (expected) results

A long time series of multi-frequency and polarization SAR datasets together with *in-situ* data will be acquired and allow to study the effects of seasonal changes on the satellite radar backscatter. It, for example, will be evaluated how stable ice type classification from SAR behaves or how the accuracy of sea ice concentration datasets change throughout the seasonal transition. The high-resolution SAR and optical data will allow to accurately monitor sea ice dynamics on a regional scale and can help to connect the observations made at the different nodes of the Distributed Network.

Tab 8.3: List of satellite datasets



Satellite Data Overview

SAR/Scatterometers *ice type, ice drift*			**Altimeters** *ice thickness, (snow depth)*			**Radiometers** *ice area, ice drift, ice thick., snow*			**Optical** *melt ponds, leads, floe size, albedo, surface temp.*			**Lidar/cloud radar** *aerosols, cloud properties, wind*		**Atmosphere** *water vapor, surfaces and TOA fluxes, gases*		
Satellite/ Sensor	Res.	Max. lat.	Satellite/ Sensor	Res.	Max. lat.	Satellite/ Sensor	Res.	Max. lat.	Satellite/ Sensor	Res.	Max. lat.	Satellite	Parameter	Satellite/ Sensor	Res.	Max lat.
Sentinel-1	90 m	88° (?)	CryoSat-2	0.3 x 1.7 km	88°	AMSR-2	4–47 km	89°	MODIS	250 m–1 km	90°	CALIPSO	aerosols/ clouds	AIRS	13–30 km	
Radarsat-2/ *RCM*	3–100 m	~89°	ICESat-2	10 m	88°	SSMIS	14–54 km	89°	VIIRS	375–750 m	90°	CloudSat	clouds	CrIS	14 km	
ALOS-2 (PALSAR-2)	3–100 m	?	SRAL (Sentinel-3)	0.3 x 1.6 km	81.5°	SMOS	40 km	88°	OLCI, SLSTR (Sentinel-3)	300 m–1 km	90°	*EarthCARE*	aerosols/ clouds	IASI	12 km	
TerraSAR-X	1–40 m	88° *(exp. 90°)*	SARAL/ Altika	1.4 km	81.5°	SMAP	40 km	87°	AVHRR	1.1 km	?	Aeolus	Wind (85°N)	GOSAT	0.5–1.5 km	
TanDEM-X	*12–30 m*	*88°*							Sentinel-2	10–60 m	83° (exp. 85°)			OCO-2	10.6 km	
COSMO-SkyMed	1–100 m	90°							Landsat 8	30–100 m	low			CERES	20 km	
SAOCOM	*10–100 m*	*?*							Pléiades	0.5–2 m	85° (87°)			GOME-2	20 km	
KOMPSAT-5	1–20 m	?							EnMAP	*30 m*	?			Sentinel-5P	7 km	
ASCAT	25 km	90°							KOMPSAT-2,3	0.5–5 m	?			AMSU-A	48 km	90°
														MHS	17 km	90°

Blue: no ordering needed
Red: needs ordering/coordination;
Green: support confirmed;
Grey: stops at <82°N;
Italic: not launched yet

Data management

All freely available satellite datasets will be stored at the MOSAiC Central Storage (MCS). Some higher resolution radar (SAR) and optical satellite datasets, however, are not freely available in full resolution to the whole MOSAiC consortium. Whenever possible (depending on the space agency contracts) reduced resolution quick-look or derived products will be stored at the MCS. Access to the full resolution, raw data products needs to be discussed with the satellite dataset PIs. PIs are not allowed to reduce access by their own judgment. However, if their contracts with the space agencies/data providers limit access they will implement these regulations in a spirit of best mutual outcome for all MOSAiC consortium members. All data are handled, documented, archived and published following the MOSAiC data policy. Exceptions will to be documented in written agreements between the data provider and the MOSAiC Project Board and data manager.

APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

A.4 DATA POLICY

A.1 TEILNEHMENDEN INSTITUTE / PARTICIPATING INSTITUTES

	Address
BE.ULIEGE	Université de Liège Allée du 6 Aout, 19 4000 Liège Belgium
CA.MANITOBA	University of Manitoba Centre for Earth Observation Science, Department of Geography 535 Wallace Building MB R3T 2N2Winnipeg Canada
CA.UCALGARY	University of Calgary Department of Geography 2500 University Drive NW T2N 1N4 Calgary Canada
CA.UVICTORIA	University Victoria Department of Geography 3800 Finnerty Road V8P 5C2Victoria, British Columbia Canada
CH.PSI	Paul Scherrer Institute Forschungsstrasse 111 5232 Villigen PSI Switzerland
CH.WSL	Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL-Institut für Schnee- und Larvinenforschung (SLF) Flüelastrasse 11 7260 Davos Dorf Switzerland
CN.BNU	Beijing Normal University No. 19, Xinjiekouwai Street 100875 BEIJING China
CN.MNR	First Institute of Oceanography No.6, Xian Xialing road 266061 Qingdao China
CN.POLAR	Third Institute of Oceanography No.178, Daxue Road 361005 Xiamen China

	Address
CN.PRIC	Polar Research Institute of China 451, Jinqiao, Pudong 200136 Shanghai China
CN.SIO	Second Institute of Oceanography Baochubei 36 310012 Hangzhou China
CN.SJTU	Shanghai Jiao Tong University No. 800 Dongchuan Road. 200240 Shanghai China
CN.USTC	University of Science and Technology of China School of Earth and Space Sciences No.96, JinZhai Road Baohe District 230026 Hefei China
COM.ALPINEWELTEN	Alpine Welten Die Bergführer GmbH & Co.KG Rauher Berg 8 89180 Berghülen Germany
COM.UCL	University College London Gower Street WC1E 6BT London United Kingdom
DE.AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Postfach 120161 27515 Bremerhaven Germany Telegrafenberg A45 14473 Potsdam Germany
DE.CAU	Christian-Albrechts-Universität zu Kiel Geographisches Institut Ludewig-Meyn-Str. 14 24098 Kiel Germany
DE.DWD	Deutscher Wetterdienst Geschäftsbereich Wettervorhersage Seeschifffahrtsberatung Bernhard Nocht Str. 76 20359 Hamburg Germany

	Address
DE.FIELAX	Fielax – Gesellschaft für wissenschaftliche Datenverarbeitung mbH Schleusenstraße 14 27568 Bremerhaven Germany
DE.FREELANCE	Kreftingstrasse 22 ETAGE 22 28203 Bremen Germany
	Döbereinerstrasse 15 7745 Jena Germany
DE.GEOMAR	GEOMAR Helmholtz-Zentrum für Ozeanforschung Paläo-Ozeanographie Wischhofstr. 1-3 24148 Kiel Germany
DE.GFZ	Deutsches GeoForschungsZentrum Telegrafenberg 14473 Potsdam Germany
DE.GUJ	Gruner&Jahr Am Baumwall 11 20459 Hamburg Germany
DE.HeliService	Heli Service International GmbH Gorch-Fock-Straße 105 26721 Emden Germany
DE.IOW	Leibnitz-Institut für Ostseeforschung Warnemünde Physikalische Ozeanographie und Messtechnik Seestraße 15 18119 Rostock-Warnemünde Germany
DE.KC	Kircher Consulting GmbH Hinterm Felde 38 27721 Ritterhude Germany
DE.LAEISZ	Reederei F. Laeisz GmbH Bartelstraße 1 27570 Bremerhaven Germany

	Address
DE.TROPOS	Leibniz Institut für Troposphärenforschung Fernerkundung atmosphärischer Prozesse Permoserstr. 15 4318 Leipzig Germany
DE.TUB	Technische Universität Braunschweig Institut für Flugführung Hermann-Blenk-Str. 27 38108 Braunschweig Germany
DE.UFA	UFA SHOW & FACTUAL GmbH Dianastraße 21 14482 Potsdam Germany
DE.UNI-Bremen	Universität Bremen Physik/Elektrotechnik Bibliothekstrasse 1 28359 Bremen Germany
DE.Uni-Leipzig	Universität Leipzig Stephanstr. 3 4103 Leipzig Germany
DE.UNITRIER	Universität Trier Behringstraße 21 54296 Trier Germany
DK.DMI	Danish Meteorological Institute Lyngbyvej 100 DK-2100 Copenhagen Ø Denmark
DK.FREELANCE	Tårnbypark Alle 41 st th 2770 Danmark Denmark
EDU.CSU	Colorado State University Atmospheric Science 1371 Campus Delivery 80523 Fort Collins United States
EDU.CU	University of Colorado Univ. of Colorado, Boulder Campus Box 216 80305 Boulder, CO United States

	Address
EDU.DARTMOUTH	Dartmouth College 14 Engineering Drive 3755 Hanover United States
EDU.FIU	Florida International University Applied Research Center 10555 W Flagler St 33174 Miami United States
EDU.ORSU	Oregon State University CEOAS Admin Bld 104 OR 97331 Corvallis United States
EDU.OSU	Ohio State University 1330 Kinnear Road 43212Columbus, OHIO United States
EDU.UAF	University of Alaska Fairbanks 2160 Koyukuk Drive PO Box 757340 99775 Fairbanks United States
EDU.UCSD	University of California, San Diego Scripps Institution of Oceanography 9500 Gilman Dr. 92093 La Jolla United States
EDU.UGA	University of Georgia 10 Ocean Science Circle 31411 Savannah, GA United States
EDU.UMD	University of Maryland Atmospheric and Oceanic Science College Park MD 20742 Maryland United States
EDU.UNI-Washington	University Washington 1013 NE 40th St Box 355640 98105 Seattle, WA United States
EDU.URI	University of Rhode Island South Ferry Rd. 2882 Narragansett United States

	Address
EDU.WHOI	Woods Hole Oceanographic Institution 266 Woods Hole Rd. 2543 Woods Hole United States
ES.ICM-CSIC	Institut de Ciències del Mar Physical and Technological Oceanography Department Passeig Marítim de la Barceloneta, 37-49 8003 Barcelona Spain
FI.FMI	Finnish Meteorological Institute Marine Research Erik Palmenin Aukio 1 100 Helsinki Finland
FI.UNI-Helsinki	Helsingin Yliopsto Institute for Atmospheric and Earth System Research P.O. Box 64 FI-00014 University of Helsinki Finland
FR.FREELANCE	POLAR Yacht Vagabond Lanton 29460 Hanvec France
FR.Univ-grenoble-alpes	Université Grenoble Alpes / CNRS Institute for Geosciences and Environmental Research 460, Rue de la Piscine Bâtiment OSUG-B 38400 Saint-Martin d'Hères France
GOV.ARM	Atmospheric Radiation Measurement TA-51 87545Los Alamos United States
GOV.NASA	National Aeronautics and Space Administration 300 E. Street SW, Suite 5R30 Washington, DC 20546 United States
GOV.NOAA	National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory 325 Broadway 80305Boulder United States

	Address
JP.HOKKAIDO	Hokkaido University Faculty of Fisheries Sciences 03.01.2001 418611 Hakodate Japan
JP.UTOKIO	University of Tokyo Atmosphere and Ocean Research Institute 5-1-5 Kashiwanoha, Kashiwa-shi Chiba 277-8564 Japan
NL.RUG	University Groningen Groningen Institute for Evolutionary Life Sciences Ecophysiology of Plants PO Box 11103 9700 CC Groningen The Netherlands
NL.WUR	Wageningen Marine Research Ankerpark 27 1781 AG Den Helder THE Netherlands
NO.FREELANCE	Operationen und Logistikk Vei 238-43A 9170 Longyearbyen Svalbard and Jan Mayen PB 319 9171 Longyearbyen Norway
NO.NPOLAR	Norsk Polarinstitutt Framsenteret Hjalmar Johansens gt. 14 9296 Tromsø Norway
NO.NTNU	Norges teksnisk-naturvitenskapelige universitet (NTNU) Høgskoleringen 7a 7034 Trondheim Norway
NO.UIB	Universitetet i Bergen P.O.Box 7800 5020 Bergen Norway
NO.UIT	Universitetet i Tromsø Hansine Hansen veg 18 9019 Tromsø Norway

	Address
ORG.BIGELOW	Bigelow Laboratory for Ocean Sciences 60 Bigelow Drive 4544 East Boothbay United States
RU.AARI	Arctic and Antarctic Research Institute Ulitsa Beringa, 38 199397 Sankt-Petersburg Russian Federation
SE.GU	Göteborgs Universitet Universitet Platsen 1 405 30Göteborg Sweden
SE.SLU	Swedish University of Agricultural Sciences, SLU Aquatic Resources Turistgatan 5 45330 Lysekil Sweden
SE.SU	Stockholms Universitet Svante Arrhenius vag 20A 10691 Stockholm Sweden
SE.UU	Uppsala Universitet Norbyv. 18D SE-75236 Uppsala Sweden
UK.BBC	BBC Global News 201 Wood Lane London W12 7TS United Kingdom
UK.BAS	British Antarctic Survey Atmosphere, Ice and Climate High Cross, Madingley Road CB30ET Cambridge United Kingdom
UK.UEA	University of East Anglia Norwich Research Park NR4 7TJ Norwich United Kingdom
UK.UHuddersfield	University of Huddersfield Biological and Geographical Sciences Queensgate HD1 3DH Huddersfield United Kingdom

	Address
UK.UNI-LEEDS	University of Leeds Woodhouse Lane LS2 9JT Leeds United Kingdom
UK.UPlymouth	University of Plymouth Drake Circus Plymouth Devon PL4 8AA United Kingdom
UK.WARWICK	University of Warwick Gibbet Hill Campus CV47AL Coventry United Kingdom
US.FREELANCE	5934 Gunbarrel Ave. Apt. B Boulder CO 80301 United States

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

A.2.1 PS122/1a

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Abrahamsson	Katarina	SE.GU	Scientist	Chemistry
Angelopoulos	Michael	DE.AWI	PhD student	other geo sciences
Argay	Peter	GOV.ARM	Engineer	Engineering Sciences
Bauch	Dorothea	DE.GEOMAR	Scientist	Physics
Blomquist	Byron	EDU.CU	Scientist	Chemistry
Boyer	Matt	GOV.ARM	Technician	Meteorology
Brooks	Ian	UK.UNI-LEEDS	Scientist	Meteorology
Castro	Vagner	GOV.ARM	Technician	Engineering Sciences
Chu	David	GOV.ARM	Technician	Chemistry
Costa	David	EDU.CU	Engineer	Meteorology
Dahlke	Sandro	DE.AWI	Scientist	Meteorology
Demir	Oguz	EDU.OSU	PhD student	Engineering Sciences
Ellis	Jody	GOV.ARM	Technician	Data
Engelmann	Ronny	DE.TROPOS	Scientist	Meteorology
Enríquez Garcia	Alberto	DE.HeliService	Technician	Helicopter Service
Fong	Allison	DE.AWI	Scientist	Biology
Gerchow	Peter	DE.AWI	Engineer	Logistics
Graupner	Rainer	DE.AWI	Technician	Oceanography
Greenamyer	Vernon	GOV.ARM	Technician	Logistics
Griess	Philipp	DE.UFA	Journalist	Media/Outreach
Griffiths	Steele	GOV.ARM	Technician	Meteorology
Grote	Sebastian	DE.AWI	Media Coordinator	Media/Outreach
Gräser	Jürgen	DE.AWI	Technician	Meteorology
Göring	Marlene	DE.GUJ	Journalist	Media/Outreach
Hall	Shannon	US.FREELANCER	Journalist	Media/Outreach
Hendricks	Stefan	DE.AWI	Scientist	Geophysics
Henning	Kirk	DE.AWI	Technician	Geophysics
Henriques	Martha	UK.BBC	Journalist	Media/Outreach
Hermansen	Gaute	DE.LAEISZ	Technician	Logistics
Hildebrandt	Nicole	DE.AWI	Scientist	Biology
Hohle	Trude	DE.LAEISZ	Advisor for Safety and Logistics	Logistics

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Honold	Hans	COM.ALPINEWELTEN	Advisor for Safety and Logistics	Logistics
Horvath	Esther	DE.AWI	Photographer	Media/Outreach
Hueber	Jacques	EDU.CU	Technician	other geo sciences
Immerz	Antonia	DE.AWI	Scientist	Data
Kieser	Jens	DE.DWD	Scientist	Meteorology
Kircher	Dietmar	DE.KC	Technician	Logistics
Kirchgaessner	Amelie	UK.BAS	Scientist	Meteorology
Kirk	Henning	DE.AWI	Technician	Geophysics
Krassovski	Misha	GOV.ARM	Engineer	Data
Kurtz	Nathan	GOV.NASA	Scientist	Physics
Käßbohrer	Johannes	DE.FIELAX	Scientist	Chemistry
König	Bjela	DE.AWI	Engineer	Logistics
Matero	Ilkka	DE.AWI	Scientist	Geophysics
Mohaupt	Verena	DE.AWI	Scientist	Logistics
Nehring	Franziska	DE.FIELAX	Scientist	Data
Nicolaus	Marcel	DE.AWI	Scientist	Geophysics
Oggier	Marc	EDU.UAF	Scientist	Geophysics
Ortega	Paul	GOV.ARM	Engineer	other geo sciences
Persson	Ola	EDU.CU	Scientist	Meteorology
Preußer	Andreas	DE.UNITRIER	Scientist	Meteorology
Quéléver	Lauriane	FI.UNI-Helsinki	PhD student	Physics
Raeke	Andreas	DE.DWD	Scientist	Meteorology
Raphael	Ian	EDU.DARTMOUTH	Student (Master)	Engineering Sciences
Regnery	Julia	DE.AWI	Scientist	other geo sciences
Rember	Robert	EDU.UAF	Scientist	Oceanography
Ren	Jian	CN.SIO	Scientist	Biology
Rex	Markus	DE.AWI	Scientist	Physics
Richman	Amy	EDU.CU	Artist	Media/Outreach
Rokitta	Sebastian	DE.AWI	Scientist	Biology
Schiller	Martin	DE.AWI	Engineer	Engineering Sciences
Schlindwein	Vera	DE.AWI	Scientist	Geophysics
Shupe	Matthew	EDU.CU	Scientist	Meteorology
Snoeijs-Leijonmalm	Pauline	SE.SU	Scientist	Biology
Spreen	Gunnar	DE.UNI-Bremen	Scientist	Physics

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Stark	Jakob	DE.UFA	Journalist	Media/Outreach
Stenssen	Willem Albertus	DE.HeliService	Technician	Helicopter Service
Stenzel	Olaf	DE.AWI	Technician	Logistics
Sterbenz	Thomas	DE.LAEISZ	Engineer	Shipping Company
Svenson	Anders	SE.SLU	Technician	Biology
Tholfsen	Audun	NO.FREELANCE	Technician	Logistics
Uin	Janek	GOV.ARM	Scientist	Physics
Verdugo	Josefa	DE.AWI	PhD student	other geo sciences
Viegas	Juarez	GOV.ARM	Engineer	Meteorology
Volgger	Ingo	DE.HeliService	Pilot	Helicopter Service
Wagner	David	CH.WSL	PhD student	other geo sciences
Zillgen	Carsten	DE.HeliService	Pilot	Helicopter Service
Zoelly	Christian	NO.FREELANCE	Technician	Logistics

A.2.2 PS122/1b

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Abrahamsson	Katarina	SE.GU	Scientist	Chemistry
Angelopoulos	Michael	DE.AWI	PhD student	other geo sciences
Archer	Steve	ORG.BIGELOW	Scientist	Oceanography
Bauch	Dorothea	DE.GEOMAR	Scientist	Physics
Blomquist	Byron	EDU.CU	Scientist	Chemistry
Castro	Vagner	GOV.ARM	Technician	Engineering Sciences
Costa	David	EDU.CU	Engineer	Meteorology
Creamean	Jessie	EDU.CSU	Scientist	Chemistry
Dahlke	Sandro	DE.AWI	Scientist	Meteorology
Demir	Oguz	EDU.OSU	PhD student	Engineering Sciences
Engelmann	Ronny	DE.TROPOS	Scientist	Meteorology
Enríquez Garcia	Alberto	DE.HeliService	Technician	Helicopter Service
Fang	Ying-Chih	DE.AWI	Scientist	Oceanography
Fong	Allison	DE.AWI	Scientist	Biology
Graeser	Jürgen	DE.AWI	Technician	Meteorology
Griffiths	Steele	GOV.ARM	Technician	Meteorology
Haapala	Jari	FI.FMI	Scientist	Oceanography
He	Hailun	CN.SIO	Scientist	Oceanography
Hendricks	Stefan	DE.AWI	Scientist	Geophysics
Hermansen	Gaute	DE.LAEISZ	Technician	Logistics
Hildebrandt	Nicole	DE.AWI	Scientist	Biology
Hohle	Trude	DE.LAEISZ	Advisor for Safety and Logistics	Logistics
Honold	Hans	COM.ALPINEWELTEN	Advisor for Safety and Logistics	Logistics
Hoppmann	Mario	DE.AWI	Scientist	Oceanography
Horvath	Esther	DE.AWI	Photographer, Media Coordinator	Media/Outreach
Immerz	Antonia	DE.AWI	Scientist	Data
Kieser	Jens	DE.DWD	Scientist	Meteorology
Kolabutin	Nikolay	DE.AARI	Scientist	Physics
Käßbohrer	Johannes	DE.FIELAX	Scientist	Chemistry
König	Bjela	DE.AWI	Engineer	Logistics
Lan	Musheng	CN.PRIC	Scientist	Biology
Lei	Ruibo	CN.PRIC	Scientist	Oceanography

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Matero	Ilkka	DE.AWI	Scientist	Geophysics
Mohaupt	Verena	DE.AWI	Scientist	Logistics
Nicolaus	Marcel	DE.AWI	Scientist	Geophysics
Oggier	Marc	EDU.UAF	Scientist	Geophysics
Persson	Ola	EDU.CU	Scientist	Meteorology
Preußer	Andreas	DE.UNITRIER	Scientist	Meteorology
Quéléver	Lauriane, Lucie, Josette	FI.UNI-Helsinki	PhD student	Physics
Raphael	Ian	EDU.DARTMOUTH	Student (Master)	Engineering Sciences
Regnery	Julia	DE.AWI	Scientist	other geo sciences
Rember	Robert	EDU.UAF	Scientist	Oceanography
Ren	Jian	CN.SIO	Scientist	Biology
Rex	Markus	DE.AWI	Scientist	Physics
Richman	Amy	EDU.CU	Artist, Media Coordinator	Media/Outreach
Shimanchuk	Egor	RU.AARI	Engineer	other geo sciences
Shupe	Matthew	EDU.CU	Scientist	Meteorology
Snoeijs-Leijonmalm	Pauline	SE.SU	Scientist	Biology
Spreen	Gunnar	DE.UNI-Bremen	Scientist	Physics
Stark	Jakob	DE.UFA	Journalist	Media/Outreach
Stennssen	Willem Albertus	DE.HeliService	Technician	Helicopter Service
Stenzel	Olaf	DE.AWI	Technician	Logistics
Sterbenz	Thomas	DE.LAEISZ	Engineer	Shipping Company
Svenson	Anders	SE.SLU	Technician	Biology
Tholfsen	Audun		Technician	Logistics
Verdugo	Maria Josefa	DE.AWI	PhD student	other geo sciences
Viegas	Juarez	GOV.ARM	Engineer	Meteorology
Volgger	Ingo	DE.HeliService	Pilot	Helicopter Service
von Schlebrügge	Nikolaus	DE.UFA	Journalist	Media/Outreach
Wagner	David	CH.WSL	PhD student	other geo sciences

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Wang	Lei	CN.BNU	PhD student	other geo sciences
Zillgen	Carsten	DE.HeliService	Pilot	Helicopter Service
Zoelly	Christian	NO.FREELANCE	Technician	Logistics

A.2.3 PS122/2

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Barthel	Lars	DE.UFA	Photographer	Public Outreach
Beck	Ivo	CH.PSI	PhD student	other geo sciences
Beck	Markus	COM.ALPINEWELTEN	Technician	Logistics
Brossier	Eric	FR.FREELANCE	Engineer	Logistics
Campbell	Robert	EDU.URI	Scientist	Oceanography
Castellani	Giulia	DE.AWI	Scientist	Physics
Cunha	Bruno	GOV.ARM	Technician	Logistics
Damm	Ellen	DE.AWI	Scientist	other geo sciences
Divine	Dmitry	NO.NPOLAR	Scientist	Oceanography
Drach	Sebastien	DE.HeliService	Pilot	Helicopter Service
Dumitrascu	Adela	SE.GU	Engineer	Oceanography
Eggers	Sarah Lena	DE.AWI	Technician	Biology
Gallagher	Michael	GOV.NOAA	Scientist	Meteorology
Ginzburg	Michael	DE.FREELANCE	Journalist	Logistics
Graeser	Jürgen	DE.AWI	Technician	Meteorology
Graupner	Steffen	DE.FREELANCE	Scientist	Geophysics
Griesche	Hannes	DE.TROPOS	PhD student	Meteorology
Griffiths	Steele	GOV.ARM	Technician	Meteorology
Grosse	Julia	DE.GEOMAR	Scientist	Biology
Haas	Christian	DE.AWI	Scientist	Glaciology
Howard	Dean	EDU.CU	Scientist	Meteorology
Huntemann	Marcus	DE.AWI	Scientist	Physics
Itkin	Polona	NO.UIT	Scientist	Geophysics
Jaggi	Matthias	CH.WSL	Technician	
Jutila	Arttu	DE.AWI	PhD student	Physics
Juul	Jesper	DK.FREELANCE	Technician	Logistics
Katlein	Christian	DE.AWI	Scientist	other geo sciences
King	Wessley	GOV.ARM	Technician	Meteorology
Kirk	Henning	DE.AWI	Technician	Geophysics
Krampe	Daniela	DE.AWI	PhD student	Physics
Kuhlmey	David	DE.AWI	Technician	Oceanography
Kuznetsov	Ivan	DE.AWI	Scientist	Oceanography
Laubach	Hannes	DE.LAEISZ	Technician	Shipping Company

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Liu	Hailong	CN.SJTU	Scientist	Oceanography
Loose	Brice	EDU.URI	Scientist	Chemistry
Mehrtens	Folke	DE.AWI	Journalist	Public Outreach
Mohrholz	Volker	DE.IOW	Scientist	Physics
Nandan	Vishnu	CA.MANITOBA	Scientist	Geophysics
Olsen	Lasse Mork	NO.UIB	Scientist	Biology
Piotrowski	Lukas	DE.HeliService	Pilot	Helicopter Service
Pliet	Johannes	DE.FIELAX	Technician	Data
Posman	Kevin	ORG.BIGELOW	Scientist	other geo sciences
Rabe	Benjamin	DE.AWI	Scientist	Oceanography
Rye	Åshild Gåsvatn	DE.AWI	Observer	Logistics
Santos Fernandez	Victor	DE.HeliService	Technician	Helicopter Service
Schneebeli	Martin	CH.WSL	Scientist	Glaciology
Schröter	Steffen	DE.DWD	Technician	Meteorology
Sheykin	Igor	RU.AARI	Scientist	Geophysics
Shimnachuk	Egor	RU.AARI	Engineer	other geo sciences
Simoes Pereira	Patric	SE.GU	Scientist	other geo sciences
Sommerfeld	Anja	DE.AWI	Scientist	Meteorology
Stephens	Mark	EDU.FIU	Scientist	Oceanography
Stroeve	Julienne	COM.UCL	Scientist	Glaciology
Tonboe	Rasmus Tage	DK.DMI	Scientist	Oceanography
Torres-Valdés	Sinhué	DE.AWI	Scientist	Oceanography
Turpeinen	Heidi	DE.FIELAX	Scientist	Data
Uttal	Taneil	GOV.NOAA	Scientist	Meteorology
Weißsohn	Jörn	DE.HeliService	Technician	Helicopter Service
Wenzel	Julia	DE.DWD	Scientist	Meteorology
Wesemann	Nina	DE.UFA	Journalist	Public Outreach
Zöphel	Zoephel	DE.AWI	Observer	Logistics

A.2.4 PS122/3 (will be submitted during the expedition)

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
			PhD student	Chemistry
			PhD student	Geology
			Scientist	Biology
			Student	Meteorology
			Student	Biology

A.2.5 PS122/4 (will be submitted during the expedition)

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
			PhD student	Chemistry
			PhD student	Geology
			Scientist	Biology
			Student	Meteorology
			Student	Biology

A.2.6 PS122/5 (will be submitted during the expedition)

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
			PhD student	Chemistry
			PhD student	Geology
			Scientist	Biology
			Student	Meteorology
			Student	Biology

A.2.7 PS122/6 (will be submitted during the expedition)

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
			PhD student	Chemistry
			PhD student	Geology
			Scientist	Biology
			Student	Meteorology
			Student	Biology

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

A.3.1 PS122/1

No.	Name	Rank
01.	Schwarze, Stefan	Master
02.	Grundmann, Uwe	1.Offc.
03.	Grafe, Jens	Ch. Eng.
04.	NN	1. Offc. Ladung
05.	Lauber, Felix	2.Offc.
06.	Peine, Lutz	2.Offc.
07.	Dr. Miersch, Wulf Dietrich	Doctor
08.	Frank, Gerhard	Comm.Of.
09.	Krinfeld, Oleksandr	2.Eng.
10.	Haack, Michael	2.Eng.
11.	NN	2. Eng.
12.	Redmer, Jens Dirk	Elec.Techn
13.	NN	Electron.
14.	Hüttebräucker, Olaf	Electron.
15.	Nasis, Ilias	Electron.
16.	Himmel, Frank	Electron
17.	Brück, Sebastian	Boatsw.
18.	Henning, Jörg	Carpenter
19.	Bäcker, Andreas	A.B.
20.	Möller, Falko	A.B.
21.	Buchholz, Joscha	A.B.
22.	NN	A.B.
23.	Decker, Jens	A.B.
24.	Wende, Uwe	A.B.
25.	Klee, Philipp	A.B.
26.	NN	A.B.
27.	Peper, Sven	A.B.
28.	Preußner, Jörg	Storek.
39.	Schwarz, Uwe	Mot-man
30.	Rhau, Lars-Peter	Mot-man
31.	NN	Mot-man
32.	Teichert, Uwe	Mot-man
33.	Gebhardt, Norman	Mot-man
34.	Schnieder, Sven	Cook
35.	Silinski, Frank	Cooksmate
36.	Möller, Wolfgang	Cooksmate
37.	Czyborra, Bärbel	1.Stwdess

No.	Name	Rank
38.	Wöckener, Martina	Stwdss/KS
39.	Dibenau, Torsten	2.Steward
40.	Silinski, Carmen	2.Stwdess
41.	Golla, Gerald	2.Steward
42.	Arendt, Rene	2.Steward
43.	Sun, Yongsheng	2.Steward
44.	Chen, Dan Sheng	Laundrym

A.3.2 PS122/2

No.	Name	Rank
01.	Schwarze, Stefan	Master
02.	Spielke, Steffen	1. Offc.
03.	Westphal, Henning	Ch. Eng.
04.	NN	1. Offc. Ladung
05.	Fischer, Tibor	2.Offc.
06.	Peine, Lutz	2.Offc.
07.	Dr. Weigand, Gerhard	Doctor
08.	Dr. Hofmann, Jörg	Comm.Offc.German
09.	NN	2. Eng.
10.	Schnürch, Helmut	2.Eng.
11.	Rusch, Torben	2.Eng.
12.	Pommerencke, Bernd	Elec.Techn German
13.	NN	Electron.
14.	Markert, Winfried	Electron.
15.	Winter, Andreas	Electron.
16.	TBN	Electron.
17.	Sedlak, Andreas	Boatsw.
18.	Neisner, Winfried	Carpenter
19.	Meier, Jan	A.B.
20.	Schade, Tom	A.B.
21.	NN	A.B.
22.	Hartwig-Labahn, Andreas A.B.	German
23.	Fölster, Michael	A.B.
24.	Müller, Steffen	A.B.
25.	Brickmann, Peter	A.B.
26.	Köpnick, Ulrich	A.B.
27.	NN	A.B.
28.	Plehn, Marco Markus	Storekeep.

No.	Name	Rank
29.	NN	Mot-man
30.	Schwarz, Uwe	Mot-man
31.	Krösche, Eckard	Mot-man
32.	Clasen, Nils	Mot-man
33.	Watzel, Bernhard	Mot-man
34.	Meißner, Jörg	Cook
35.	Tupy, Mario	Cooksmate
36.	Martens, Michael	Cooksmate
37.	Wartenberg, Irina	1.Stwdess
38.	Pommerencke, Kerstin	Stwd/KS
39.	Hischke, Peggy	2.Stwdess
40.	Bachmann, Julia Maria	2.Stwdess
41.	Krause, Tomasz	2.Steward
42.	Hu, Guo yong	2.Steward
43.	Chen, Quan Lun	2.Steward
44.	Ruan, Hui Guang	Laundrym.

A.3.3 PS122/3

No.	Name	Rank
01.	Schwarze, Stefan	Master
02.	Grundmann, Uwe	1. Offc..
03.	Grafe, Jens	Ch. Eng.
04.	NN	1. Offc. Ladung
05.	Fischer, Tibor	2.Offc.
06.	Hering, Igor	2.Offc.
07.	Dr. Gößmann-Lange, Petra	Doctor
08.	Dr. Hofmann, Walter- Jörg	Comm.Of.
09.	Brose, Thomas	2.Eng.
10.	Haack, Michael	2.Eng.
11.	NN	2. Eng.
12.	Ruppert, Enrico	Elec.Techn
13.	NN	Electron.
14.	Hüttebräucker, Olaf	Electron.
15.	Winter, Andreas	Electron.
16.	Himmel, Frank	Electron
17.	Brück, Sebastian	Boatsw.
18.	Reise, Lutz	Carpenter
19.	Bäcker, Andreas	A.B.
20.	Möller, Falko	A.B.

No.	Name	Rank
21.	Buchholz, Joscha	A.B.
22.	NN	A.B.
23.	Burzan, Gerd-Ekkehard	A.B.
24.	Wende, Uwe	A.B.
25.	Klee, Philipp	A.B.
26.	NN	A.B.
27.	Peper, Sven	A.B.
28.	Preußner, Jörg	Storek.
29.	Waterstradt, Felix	Mot-man
30.	Rhau, Lars-Peter	Mot-man
31.	NN	Mot-man
32.	Teichert, Uwe	Mot-man
33.	Gebhardt, Norman	Mot-man
34.	Schnieder, Sven	Cook
35.	Silinski, Frank	Cooksmate
36.	Möller, Wolfgang	Cooksmate
37.	Krause, Tomasz	1.Stwdess
38.	Wöckener, Martina	Stwdss/KS
39.	Dibenau, Torsten	2.Steward
40.	Silinski, Carmen	2.Stwdess
41.	Golla, Gerald	2.Steward
42.	Arendt, Rene	2.Steward
43.	Sun, Yongsheng	2.Steward
44.	Chen, Dan Sheng	Laundrym.

A.3.4 PS122/4 and PS122/5

No.	Name	Rank
01.	Wunderlich, Thomas Wolf	Master
02.	Spielke, Steffen	1. Offc.
03.	Westphal, Henning	Ch. Eng.
04.	NN	1. Offc. Ladung
05.	Kentges, Felix	2.Offc.
06.	Hering, Igor	2.Offc.

No.	Name	Rank
07.	Dr. Miersch, Wulf Dietrich	Doctor
08.	Frank, Gerhard	Comm.Offc.German
09.	NN	2. Eng.
10.	Schnürch, Helmut	2.Eng.
11.	Rusch, Torben	2. Eng.
12.	Pommerencke, Bernd	Elec.Techn German
13.	NN	Electron.
14.	Markert, Winfried	Electron.
15.	Nasis, Ilias	Electron.
16.	TBN	Electron.
17.	Sedlak, Andreas	Boatsw.
18.	Neisner, Winfried	Carpenter
19.	Meier, Jan	A.B.
20.	Schade, Tom	A.B.
21.	NN	A.B.
22.	Decker, Jens	A.B.
23.	Fölster, Michael	A.B.
24.	Müller, Steffen	A.B.
25.	Brickmann, Peter	A.B.
26.	Köpnick, Ulrich	A.B.
27.	NN	A.B.
28.	Plehn, Marco Markus	Storekeep.
29.	NN	Mot-man
30.	Waterstradt, Felix	Mot-man
31.	Krösche, Eckard	Mot-man
32.	Clasen, Nils	Mot-man
33.	Watzel, Bernhard	Mot-man
34.	Meißner, Jörg	Cook
35.	Tupy, Mario	Cooksmate
36.	Martens, Michael	Cooksmate
37.	Wartenberg, Irina	1.Stwdess
38.	Pommerencke, Kerstin	Stwd/KS
39.	Hischke, Peggy	2.Stwdess
40.	Bachmann, Julia Maria	2.Stwdess
41.	TBN	2.Steward
42.	Hu, Guo yong	2.Steward
43.	Chen, Quan Lun	2.Steward
44.	Ruan, Hui Guang	Laundrym.

A.3.5 PS122/5 (2nd half) and PS122/6

No.	Name	Rank
01.	Wunderlich, Thomas Wolf	Master
02.	Grundmann, Uwe	1.Offc.
03.	Grafe, Jens	Ch. Eng.
04.	NN	1. Offc. Ladung
05.	Fischer, Tibor	2.Offc.
06.	Peine, Lutz	2.Offc.
07.	TBN	Doctor
08.	Frank, Gerhard	Comm.Of.
09.	Krinfeld, Oleksandr	2.Eng.
10.	Haack, Michael	2.Eng.
11.	NN	2. Eng.
12.	Redmer, Jens	Elec.Techn
13.	NN	Eletron.
14.	Hüttebräucker, Olaf	Electron.
15.	Winter, Andreas	Electron.
16.	Himmel, Frank	Electron
17.	Brück, Sebastian	Boatsw.
18.	Reise, Lutz	Carpenter
19.	Bäcker, Andreas	A.B.
20.	Möller, Falko	A.B.
21.	Buchholz, Joscha	A.B.
22.	NN	A.B.
23.	Burzan, Gerd-Ekkehard	A.B.
24.	Wende, Uwe	A.B.
25.	Klee, Philipp	A.B.
26.	NN	A.B.
27.	Peper, Sven	A.B.
28.	Preußner, Jörg	Storek.
29.	Schwarz, Uwe	Mot-man
30.	Rhau, Lars-Peter	Mot-man
31.	NN	Mot-man
32.	Teichert, Uwe	Mot-man
33.	Gebhardt, Norman	Mot-man
34.	Schnieder, Sven	Cook
35.	Silinski, Frank	Cooksmate
36.	Möller, Wolfgang	Cooksmate

No.	Name	Rank
37.	Czyborra, Bärbel	1.Stwdess
38.	Wöckener, Martina	Stwdss/KS
39.	Dibenau, Torsten	2.Steward
40.	Silinski, Carmen	2.Stwdess
41.	Golla, Gerald	2.Steward
42.	Arendt, Rene	2.Steward
43.	Sun, Yongsheng	2.Steward
44.	Chen, Dan Sheng	Laundrym.