MOSAiC

Multidisciplinary drifting Observatory
for the Study of Arctic Climate

Implementation Plan

April 2018

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SUMMARY

This document is the second version of the Implementation Plan for the ***M**ultidisciplinary drifting **O**bservatory for the **S**tudy of **A**rct**i**c **C**limate* (MOSAiC) initiative and lays out a vision of how associated observational, modeling, synthesis, and programmatic objectives can be manifested. The document was drafted during an international workshop in Potsdam in July 2015, and further developed during two additional workshops at AWI Potsdam in December 2015 and February 2016. Support for this planning activity has been provided by the IASC-ICARPIII process, the Alfred Wegener Institute Helmholtz Centre for Polar- and Marine Research, and the University of Colorado/ NOAA-ESRL-PSD. This document provides a framework for planning the logistics of the project, developing scientific observing teams, organizing scientific contributions, coordinating the use of resources, and ensuring MOSAiC's legacy of data and products. A brief overview and summaries of key science questions are provided in Section 1. Section 2 includes an overview of specific observational requirements, while Section 3 describes the coordination and design of specific field assets. Practical logistics plans are outlined in Section 4. Links with current and future satellite programs and model activities are given in Sections 5 and 6. The MOSAiC data management strategy is given in Section 7. Links to other programs are outlined in Section 8. The appendix (Section 9) lists the parameters to be measured and the participating groups.

This document reflects the status of the MOSAiC implementation plan in April 2018. The MOSAiC consortium is open and welcomes further contributions from the scientific community. As a result of this ongoing process new partners and scientific activities will be added and the implementation plan will continue to evolve.

1. BACKGROUND AND OVERARCHING GOALS OF MOSAiC

Changes in the Arctic sea ice system both causing and amplifying the current dramatic Arctic warming have substantially affected Arctic regional weather and climate, and are globally relevant. There are still some major gabs in our understanding of how these local and regional changes are unfolding and how they interact with, and affect, the weather and climate of the Northern Hemisphere. The improvement of our knowledge on processes determining the complicated Arctic climate system remains a major challenge. The basis of this challenge resides in the nonlinear dynamics of the coupled system that involves the atmosphere, ocean, sea ice, bio-geochemical cycles and feedbacks, e.g., with the ecosystem. These interacting processes in the Arctic climate system manifest on many different spatial and temporal scales ranging from local processes in the Arctic itself (e.g., heat fluxes through leads), to synoptic scales (e.g., cyclogenesis in warming regions), and further to planetary waves and large-scale patterns such as the atmospheric Arctic Oscillation and the Meridional Overturning Circulation in the Atlantic Ocean. It is widely recognized the lack of observations in the Central Arctic, in particular in winter, inhibits a progressing understanding and model representation of the Arctic climate system. Observations of cloud properties, surface and free-atmosphere energy fluxes, aerosol particles, planetary boundary layer structure, thin sea ice dynamics, effects of snow on sea ice, ocean stratification, gas transfer, biological feedbacks with ice and ocean, and other factors are extremely scarce (or even non-existing) in the Central Arctic, especially over the course of a full annual cycle and collected in a complementary and coordinated way promoting synergistic collaboration. To understand the evolving Arctic climate system, and the role it plays in a changing global climate, requires detailed observations and improved representation of these Arctic climate properties and coupled processes.

Fig 1.1: Illustration of the layout of the main elements of the MOSAiC experiment: Polarstern is moored to the central observatory and it is surrounded by the distributed network and connected to the larger scales though airborne measurements, other research vessels and satellites. The illustration of the ice camp sketches the different installations and research areas on, above, and under the sea ice. (Figure: Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI)/Martin Künsting CC-BY 4.0).

MOSAiC is an international initiative developed under the International Arctic Science Committee (IASC) umbrella that aims to improve numerical model representations of Arctic sea ice, weather, climate, biogeochemical- ecosystem processes through coupled system observations and modeling studies that link the central Arctic atmosphere, sea ice, ocean, bio-geochemistry and ecosystem. IASC has adopted MOSAiC as a key international collaborative activity and flagship Arctic research project to address these priority research needs in the Central Arctic. The MOSAiC plan is to make coordinated measurements of Central Arctic coupled processes over a full annual cycle, and over representative spatial scales, to support flexible and generalized representations in models. In this regard MOSAiC offers an important opportunity to gather the high quality and comprehensive observations that are needed to improve numerical modeling of critical, scale-dependent processes that impact Arctic predictability given diminished sea ice coverage, increased model complexity, and the movement towards coupled-system models. To facilitate, evaluate, and develop the needed model improvements, MOSAiC will employ a hierarchy of modeling and synthesis approaches ranging from process model studies, to regional climate model inter-comparisons, to operational forecasts and assimilation of real-time observations into weather prediction models. The main scientific goals for the initiative are outlined at length in the MOSAiC Science plan (www.mosaic-expedition.org) and were based on a series of workshops held in Potsdam and Boulder between 2011 and 2014. Important themes include: sea ice energy budgets and boundary layers; ice dynamics; clouds, precipitation, and aerosols; sources, sinks and cycles of chemical species and bio-geochemical cycles; biologically mediated transformations of carbon and other essential elements relevant to ecosystem structure and function; assimilation for operational weather prediction models and sea ice forecasts; ground validation for satellite remote sensing; and stakeholder services. For each of these themes, specific guiding science questions and corresponding measurement objectives will be briefly summarized.

Energy budgets and boundary layers

- How does the transfer of energy through the atmosphere-ice-ocean column depend on the surface properties?
- How do atmosphere and ocean boundary layer stratification and structure evolve with season?
- What role do transient processes play in vertical mixing?

The energy budget of sea ice is a significant control on the overall ice mass, and is influenced by a variety of coupled processes acting within the sea ice itself, in the atmospheric boundary layer, and in the ocean boundary layer, with interactions among these components. It is essential to characterize all aspects of this system. Within the ice this includes quantifying fluxes of energy at both top and bottom interfaces and the flow of energy through ice via conduction and transmission. Surface heterogeneity is very important as it determines the spatially integrated energy transfer. Thus it is critical to characterize both the spatial variability of surface conditions (ice thickness, ice morphology, lead and melt pond fractions, snow depth, albedo) and the sensitivity of energy transfer processes to the spatial surface type distribution as it evolves with season. Energy transfer to the sea ice depends on the vertical and horizontal structure of atmospheric and oceanic properties. The atmosphere, and its boundary layer structure, is important through its impact on vertical buoyant and mechanical mixing of heat, and through a host of spatially and temporally variable processes that control radiation budgets. Important processes occur at local scales but are driven by synoptic-scale forcing that influences temperature and moisture advection, boundary layer stability, and other modes of variability. Important processes in the upper ocean include mixing induced by haline convection during freezing, local momentum fluxes, and large-scale ocean dynamics. The background stratification near the surface and in the halocline below influence vertical fluxes of heat and salt (freshwater), which must be understood relative to mixing with warm reservoirs of ocean heat below. Within both ocean and atmosphere domains it is important to understand the unique Arctic annual cycles in boundary layer stratification, and the interactions of the stratified state with mesoscale variability, including transient events driven by storms, internal waves, eddies, and/or topography.

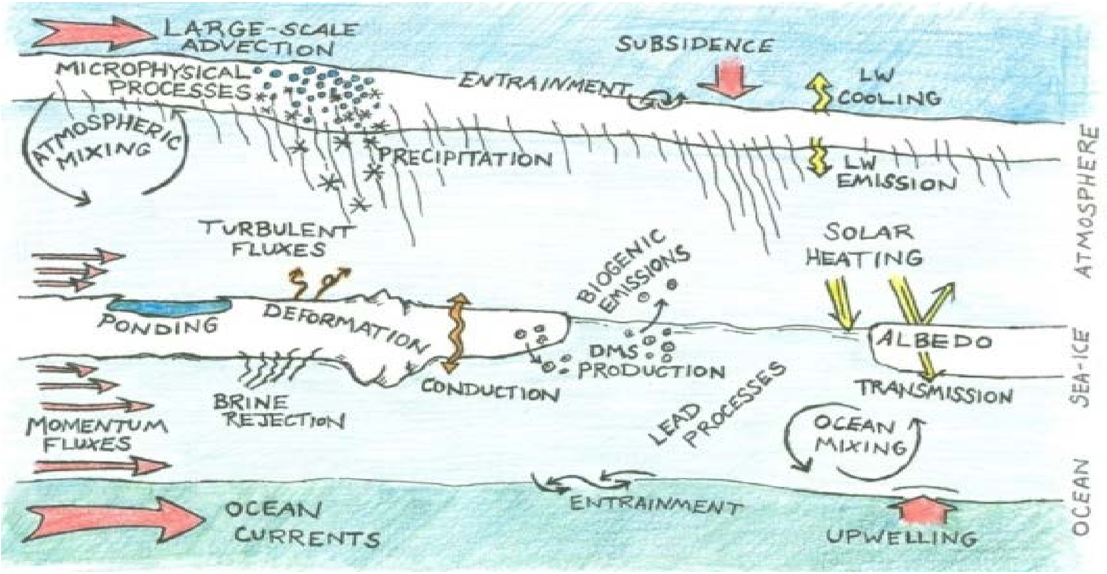


Fig. 1.2: Illustration of the interaction of the manifold processes between the different spheres of MOSAiC. (Figure: M. Shupe).

Sea ice dynamics

How does young, thin sea ice move and deform relative to thick ice?

- How do surface roughness and momentum transfer depend on sea ice state and season?
- How do dynamics contribute to the time evolution of ice thickness distribution?

In addition to thermodynamic processes, sea ice properties and spatial distribution are strongly influenced by ice dynamics and deformation. Deformation is a key process that determines the evolution of surface type and the floe size distribution, and it depends on both the state and movement of the ice. To understand these processes requires characterizing the distribution of ice drift velocities in a non-uniform ice pack, which is in part coupled to momentum transfer from the atmosphere and ocean. Constraining this system requires statistically representing the ice top and bottom roughness lengths (and thereby drag coefficients), and how these vary in time, space, and throughout the ice lifecycle. Processes that are responsible for determining surface roughness are also important, such as lead formation, pond processes, snow re-distribution, ridging, and the evolution of bottom topography, some of which are related to ice age. Moreover, there are important feedbacks between deformational processes, such as lead formation, and additional thermodynamic growth of ice. In certain seasons and conditions, wave-ice interactions can also play a role in both ice formation and deformation. Multiscale constraints are needed on all aspects of this system for developing the best representation of ice rheology in models.

Clouds, precipitation, aerosols

- What processes determine the phase partitioning and radiative effects of clouds?
- How is snowfall partitioned between periodic storms and persistent shallow cloud systems?
- What are the baseline aerosol bulk and radiative properties in the Central Arctic and how are these affected by source regions, aging, and processing?

Clouds, precipitation, and aerosols are significant modulators of atmospheric energy fluxes to the Arctic surface and represent some of the largest sources of uncertainty in models at all scales due to their complexity and a lack of observations. It is essential to thoroughly characterize their background states and their primary modes of variability. For clouds, the main factors that control their influence are phase composition and persistence. A robust partitioning of cloud mass between liquid and ice is required, as well as the cloud microphysical composition as it relates to radiative properties. Additionally, the specific roles of moisture variability, aerosol properties, and dynamical influences on cloud formation as a function of season must be characterized. Within the atmosphere, precipitation processes are important as a sink of atmospheric moisture and modulator of cloud lifetime. It also influences the spatial distribution of snow on the surface, and thus the surface albedo. Precipitation should be characterized as a function of season and cloud type. Through direct influences on radiation and indirect controls on clouds and precipitation, aerosols play a foundational, yet unclear role, in the Central Arctic system. An enhanced characterization of the aerosol lifecycle is needed that includes understanding aerosol sources (both local and advected), particle size distributions, chemical composition and transformation, and cloud-active properties, among others. The role of black carbon should also be characterized, both through absorption in the atmosphere and modifications to surface albedo.

Sources, sinks and cycles of chemical species

- How do surface fluxes of trace gases, aerosols and aerosol precursors depend on environmental conditions (e.g. light, turbulence, ice/snow conditions, etc.)?
- What role does sea ice play in the carbon cycle as a function of season?

Numerous bio-geochemical cycles of climate relevance cut across the Arctic sea ice – ocean – atmosphere system, and these are not well measured or understood. In this coupled system there are many important pathways and sub-systems to consider, including fluxes among the atmosphere, ice, and ocean, the influence of surface freeze/melt, and the central role of biological uptake and release of key chemical species such as O_2 and CO_2. It is also important to characterize the regional sources and mechanisms for halogen activation, and to further understand how halogens affect tropospheric ozone and oxidation capacity, which can influence gases such as methane. The carbon cycle is also critical, and numerous relevant processes vary throughout the year. For example, while biological activity within sea ice is a seasonal source of methane, the sea ice can also serve as a buffer for methane fluxes. The seasonality of these processes as potential sources and sinks must be constrained. Additionally, dimethylsulphide (DMS) is an important natural source of sulfur to the atmosphere, where it can be oxidized to form sulfate aerosols that affect cloud formation. It is critically important to understand the biological community responsible for DMS production and the seasonal controls on its flux to the atmosphere. For all of these cycles, it is necessary to understand gas exchange processes and rates among the ocean, ice, and atmosphere, which are related to the variable surface conditions, stratification in ocean and atmosphere, and mixing processes. Moreover, re-deposition processes serve as another important link in these cycles. A full annual cycle of solar radiation and surface conditions, including sea ice freezing and melting cycles, is a prerequisite for understanding the coupling between ice physics, biology and bio-geochemical processes near the surface interface. At higher altitudes, dynamical coupling between the troposphere and stratosphere can affect stratospheric ozone chemical cycles, with implications via large-scale radiative feedbacks that must be understood.

Role of biology in mediating key fluxes

- How does the balance between primary production and respiration in sea ice and the water column mediate both the stoichiometry and fluxes of climate-relevant and essential ecosystem elements (i.e. carbon, nitrogen, oxygen?
- How do microbial and faunal communities, and their interactions with each other mediate these fluxes, and what are the physical, chemical, and biological processes that control their distribution and activity?
- What role does sea ice play in shaping and altering ecological processes as a function of short-term events and seasonal transitions?

Biological processes in sea ice and underlying waters play crucial roles in bio-geochemical cycles. To understand how atmospheric and ocean elemental fluxes are modified by ecosystem processes requires an integrated estimate of energy and elemental transformations driven by biota. Year-round observations of biological standing-stocks and elemental fluxes (e.g., carbon (C), nitrogen (N), and oxygen (O)), particularly in the polar night are lacking. Therefore, our present understanding of the coupling between different Arctic system components, and prediction of future changes to the Arctic climate system are hindered. Furthermore, we need to increase both the total number and frequency of synoptic observations to extend our knowledge of how distributions and activities of organisms drive elemental fluxes in response to physical conditions (i.e., ice cover, stratification, distribution of water masses). Physical-biological interactions directly impact production of C, N, and O, as well as both the recycling and vertical transport of organic matter across interfaces. In particular, the variation in the strength of the biological pump, which drives organic matter export from sea ice and the water column to the benthos, requires greater resolution over the annual cycle. Dissolved organic matter concentrations and characteristics (DOM), are poorly constrained despite their direct linkages to critical processes such as DMS production (above), nutrient recycling, and microbial food web dynamics. Thus, both the dissolved and particulate pools of the carbon and other essential elements mediated by biological processes require further investigation in the context of the annual cycle. Biological productivity in the Arctic is often limited by the availability of nitrogen sources to primary producers. Light and nutrients play important, complementary roles in regulating the onset, magnitude, and decline of primary productivity in both sea ice and pelagic ecosystems. Changes in and controls on primary production in the Central Arctic are critical to our understanding of ecosystem function and climate feedbacks regulated by ecological processes. Both primary and bacterial production will be measured throughout the year to examine the temporal relationship between the physical, chemical, and biological factors that drive production at the base of the food web. Additionally, a key focus will be the microbial recycling of various forms of C and N through organic matter remineralization. Measurements of elemental fluxes mediated by zooplankton, and larger mesozooplankton grazers will also be necessary to understand linkages of these processes across trophic levels. Therefore, it is necessary to combine and link the physical and ecological processes underpinning observations of both biogeochemical and biological components of the Central Arctic ecosystem.

It is critical to survey sea ice and under-ice biota in high-latitude ecosystems as they are key players in biogeochemical cycling and serve as valuable food sources fueling higher trophic levels in the Arctic. Measurements of sympagic and pelagic bio- and functional diversity, community structure, and biomass are necessary to elucidate their roles in ecosystem structure and function. Additionally, studies of ecological or behavioral strategies (e.g., cues for bloom initiation, vertical depth preferences and diel or ontogenic vertical migration) and life history patterns (e.g., reproductive timing and overwintering strategies) particularly for zooplankton, are needed to gain mechanistic understanding of how these organisms respond and interact to environmental changes. Seasonal changes in food web structure and interactions strongly affect biological carbon cycling. Linking diversity and food web studies using various food web tracers will further improve our knowledge of biogeochemical and ecosystem level processes in the high Arctic. Coordinated experiments to quantify transformations of carbon, nitrogen, and other essential elements will be conducted to constrain transformation rates over the annual cycle, and during episodic and seasonal events. A combination of high resolution observations and measurements, coupled to process and rate studies are needed to inform, validate, and improve state-of-the-art biogeochemical and climate modeling of the future Arctic Ocean.

Data assimilation for operational models and sea ice forecasts

- What influence does routine atmospheric profile assimilation data have on representing the large-scale circulation of the central Arctic?
- What influence does additional assimilation data have on forecast errors for both Arctic and mid latitudes?

Globally, atmospheric profile information from numerous observations including radiosondes is assimilated into numerical weather prediction models (NWP) and atmospheric reanalysis, and thereby serves as a valuable constraint on large-scale atmospheric circulation. Relatively limited observational data is available in the Arctic for routine assimilation. Past studies of periodic enhanced Arctic radiosonde data have shown that assimilation of these added temperature and humidity measurements can improve both the initial model state and reproducibility of large-scale atmospheric circulation patterns such as cyclones, having impacts across the Arctic and even down to mid-latitudes. The MOSAiC drift offers the unique opportunity to conduct comprehensive data assimilation studies by providing a yearlong radiosonde data set within the Central Arctic. Moreover, the potential for increased radiosonde frequency at Arctic coastal sites and/or from other vessels in the Arctic Ocean on the same time frame further enhances this unprecedented opportunity to understand the impact of more frequent assimilation data on operational weather forecast models and reanalysis in this data sparse region. Increased assimilation data has the specific potential to improve understanding of the atmospheric circulation and the representation of the local processes such as boundary layer, radiation, and turbulent surface heat, moisture and momentum fluxes. Such improvements are strongly needed since the effect of changes in Arctic sea ice and snow cover are transferred to the atmosphere through these processes. The potential of Arctic change to affect atmospheric baroclinic circulation, and thereby the large-scale linkage between the Arctic and mid-latitudes, depends on the magnitude and vertical/horizontal extent of anomalies in air temperature and moisture, which are intimately connected with these surface processes.

Satellite remote sensing of the sea ice cover

- How well do satellite algorithms perform in the Central Arctic for parameters such as sea ice thickness distribution, snow depth, ice type, floe size 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, and snow depth?
- Can satellite observations be used to upscale detailed regional information to pan-Arctic domains?

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 or from altimeters, measuring different kinds of 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. 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.

Stakeholder services

In addition to advances in scientific understanding of the changing Arctic coupled system, MOSAiC measurements and their resulting analyses will contribute to numerous key stakeholder needs and services. These include:

- Improved regional and hemispheric short-term weather forecasts via assimilation studies and improvements in physical parameterizations;
- Improved parameterizations for climate models that will facilitate understanding, prediction and projections of the changing Arctic climate on inter-annual and decadal time scales;
- Improved sea ice forecasts on daily, seasonal, and inter-annual time scales through process understanding, assimilation studies, and improved coupled system model representations;
- Enhanced utility of long-term satellite observations and ice services through advanced ground validation and evaluation;
- Enhanced observing system for the Arctic region by promoting the development and field testing of autonomous sensors;
- Relevant impacts on socio-economic sectors with respect to: ocean productivity, fisheries, and food supplies; Arctic shipping and Northern Sea Routes; resource development via mining and oil/ gas exploration.

2. MEASUREMENTS AND REQUIREMENTS

To achieve the MOSAiC science and programmatic objectives will require a specific set of measurements, which are outlined here along disciplinary teams. This disciplinary approach is necessary to most easily coordinate the many different components of, and contributions to, the initiative. It is obviously of fundamental importance to implement these disciplinary measurements and observations in a coordinated way to promote cross-disciplinary, coupled system research over the full annual cycle and on different spatial scales.

A Central Observatory (CO), based on and around the German research icebreaker Polarstern, will be the centerpiece of the MOSAiC installation. It will serve as a platform for many measurements, laboratory space for research, and a base for personnel. Near the Polarstern (<1km) will be an ice camp that is the base of operations for measurements that require some distance from the ship and its associated environmental impacts. Together the Polarstern and ice camp will be called the Central Observatory. This Central Observatory will be surrounded by a Distributed Network (DN) comprised of autonomous systems deployed at multiple scales. The Central Observatory and Distributed Network will drift together and comprise the MOSAiC constellation for continuous measurements.

The following sections summarize the disciplinary measurement requirements that are needed for MOSAiC to achieve its interdisciplinary science objectives. The exact type as well as spatial and temporal coverage will often vary over the annual cycle with most intensive measurements during Intensive Observation Periods (IOPs). Ground truth measurements for satellite observations are implicitly included in the observations on Polarstern, in the distributed network, and during airborne measurements.

Each of these measurement domains will be described in detail in this section.

Detailed lists of required parameters are given as tables in the Appendix (Section 9.1). These tables also list the respective methods in connection with instrumentation needed and the concept of measurement frequencies on all spatial scales.

2.1 Atmosphere (team ATMOS)

Atmospheric variability occurs on many scales in both the vertical and horizontal. Moreover, atmospheric processes are intimately linked with processes in the ice and ocean. Within the atmosphere domain, observations during the MOSAiC campaign will be carried out at the central observatory on RV Polarstern, at the nearby ice camp, and across the distributed network of observing stations. The measurements cover a range of essential climate variables (ECVs), most of which will be recorded continuously throughout the whole campaign. In addition, some dedicated observations are foreseen for shorter-term IOPs. Furthermore, airborne observations will utilize the AWI Polar aircraft, as well as several other fixed wing and helicopter aircraft plus Unmanned Aerial Vehicles (UAVs) to be operated for selected times during daylight periods.

The main atmospheric science topics as described in the MOSAiC Science Plan are:

1. Surface energy budget
2. Atmospheric boundary layer
3. Clouds, precipitation, and aerosols
4. Air – sea gas exchange

The corresponding observations will be at the central observatory, which will comprehensively measure the structure and properties of the atmospheric column above and its vertical column interactions (like the radiation budget). This includes surface observations by in situ instruments, active and passive ground-based remote sensing, and free flying and tethered balloons.

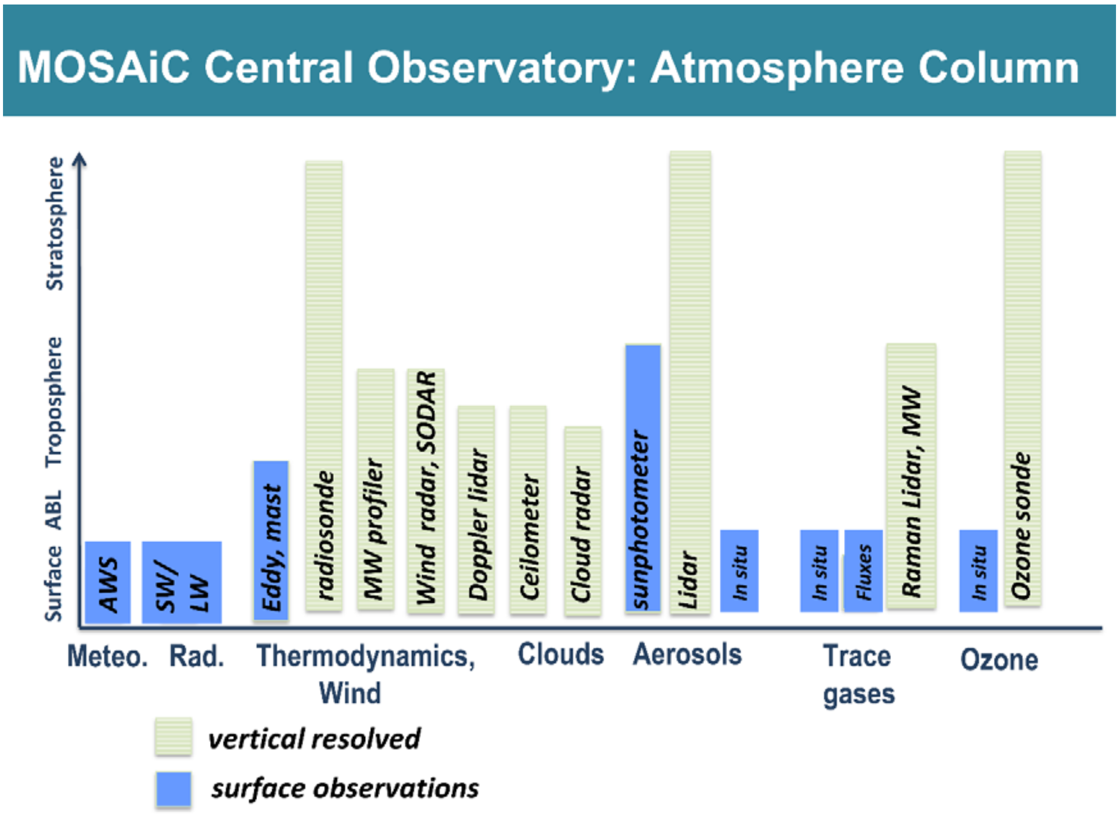


Fig. 2.1: Components and instrumentation for the measurement of the Atmosphere Column at the Central Observatory. MW represents the microwave radiometer. (Figure: R. Neuber (AWI)).

Work on Polarstern

The installations onboard RV Polarstern consist of those that need high electrical power, that are not readily deployed on the sea ice, and are not strongly influenced by the ship. These include containerized active and passive remote sensing instruments like radars, radiometers, and lidars, as well as balloon soundings of meteorological parameters and ozone. Some atmospheric sensors will be installed independently on top of the bridge and on the crow's nest and bow of the ship. For a number of atmospheric sensors, particularly remote sensors that scan in space, a clear view of the sky in multiple directions is necessary. These instruments will be given priority access to specific installation locations to minimize interference from ship infrastructure. Laboratory space for sampling, analyzing, and/or treatment of air samples is needed. To facilitate air sampling, inlet systems will be designed and installed to minimize and monitor contamination from ship pollution. Work on Polarstern will include the maintenance of probes for the helicopter and/or UAV surveys flying from Polarstern.

Work on ice camp

Many observations will be made some distance away from the ship to avoid its disturbance in terms of flow modifications, radiative signatures, exhaust, etc. Therefore, the atmosphere part of the ice camp will be sufficiently distant from the ship (up to 500 m) and other obstructing installations, like generators. The "Met City" of the ice camp will be the farthest permanent installation from the ship and will include automated weather stations, precipitation measurements, a meteorological mast(s), and dedicated installations for surface energy flux measurements including radiation and turbulence. Any tethered balloon operations will also occur from the ice, although not as far from the ship as the other on-ice atmospheric measurements.

Distributed network

A distributed network of meteorological observations will be implemented on scales of 10-30 km, similar to model grid box scales, to characterize spatial heterogeneity and the dependence of atmospheric conditions on variable surface parameters. Since atmospheric measurements are typically difficult to make autonomously, due to the complexity of many atmospheric instruments and the challenging environmental conditions, distributed ground-based atmospheric measurements will be limited to near-surface meteorological measurements and surface energy fluxes, including radiative and turbulent heat fluxes. The constellation will include at least three remote atmospheric surface flux measurement stations, and many other autonomous weather stations, to be coordinated with autonomous stations for making measurements in the ice and ocean, and to represent multiple ice/surface types. A portable meteorology and surface flux measurement system is also desirable for deployment to opportunistic features such as leads that open during the course of the observing campaign.

To interface with spatial measurements made across the distributed network, the spatial distribution of some atmospheric measurements will also be made via scanning remote sensors installed at the Central Observatory. Scanning precipitation radar will observe precipitation at scales of multiple 10s of km, while scanning Doppler lidar will observe aerosol backscatter and winds at scales of multiple km, depending on conditions. These scanning remote sensors will be operated continuously during the campaign.

Deployments of research aircraft (externally based, fixed wing planes, as well as Polarstern based helicopters and UAVs) will serve to horizontally extend the observations considerably, but will likely be limited to day light operation conditions (depending on RV Polarstern safety regulations). UAVs operated from the ship and/or ice camp will be used to obtain spatial measurements of atmospheric state, aerosol properties, surface type, and surface turbulent heat fluxes. Due to complexities of operating UAVs, it is anticipated that these measurements will not be continuous for the full duration of the field campaign but will instead be episodic.

2.2 Sea Ice and Snow Cover (team ICE)

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 team are distributed on all observational components and spread over all scales. Together, the implemented measurements will serve the following science objectives from the science plan:

1. Completely characterize the properties of the snow and ice cover at the central observatory, their spatial and temporal variability, and understand the processes that govern these properties
2. Determine the mass and fresh water balances at the central observatory
3. Determine the partitioning of solar radiation at the central observatory
4. Describe the spatial and temporal variability of ice thermodynamics and dynamics on regional scales
5. Integrate sea ice measurements with other components at multiple scales
6. Transfer 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 first 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 of leads, deformed ice, weathering and melting ice. A freezer lab container will be used to process snow and sea ice samples throughout the year.

Work on Polarstern

Different small installations are necessary on Polarstern in order to monitor the snow and ice conditions surrounding 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 in the snow and sea ice team.

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 will be divided into 3 sub-tasks with according parameters and methods (see Figure 2.2):

Mass balance

- Sea ice thickness, snow depth, freeboard through: repeated transects (airborne and ground, drilling and non-destructive), hot wires and stakes, snow radar and electromagnetics
- Surface topography and snow redistribution through terrestrial and airborne laser scanning and particle counters
- Lateral melt through stakes and multi-beam mapping of the ice bottom (ROV, AUV)
- Floe size distribution through photo cameras (airborne) and ship radar
- Surface roughness and false bottoms though LIDAR, ROV multi-beam and video
- Depth, geometry and coverage of melt ponds through repeated surveys with cameras (visual, infrared, hyperspectral)
- 3D mapping of ridges through structure by motion (airborne), bottom topography from ROV/AUV missions and surface laser scanning

Energy budget

- Spectral albedo and transmission through radiation stations, repeated transects (surface, airborne and ROV/AUV) and airborne hyper-spectral camera
- Impurities and inherent optical properties through sampling and profiling
- Surface temperature and properties through thermistor chains, IR cameras and LIDAR
- Surface classification through airborne photography and radar

Properties of snow, sea ice and melt ponds

- Snow texture, temperature, density, salinity, O18, and snow water equivalent through snow pits and sampling (partly also through autonomous measurements)
- Snow grain size, specific surface area through snow pits and Ice Cube measurements
- Stratigraphy and micro-structure through snow pits and computer Tomography
- Density, hardness, snow-water equivalent through penetrometer
- Temperature through thermistor chains, manual profiles, IR surface temperature
- Black carbon and chemical properties through Sun Photometer measurements
- Large scale surface properties through airborne transects with imaging systems
- Sea ice porosity through Multi-frequency EM
- Surface temperature through IR temperature (KT19)
- Melt ponds salinity and water properties through sampling
- Deformation and shear through ship radar and high resolution position (GNSS)
- Stress and strain though strain gauge sensors on Polarstern

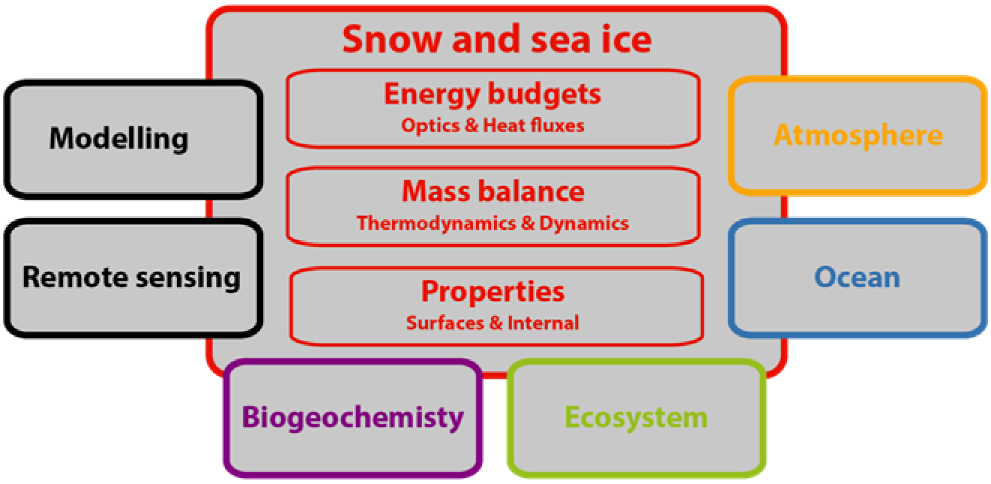


Fig. 2.2: Schematic interaction of the five sub-tasks within the snow and sec ice team with other. (Figure: M. Nicolaus (AWI))

Beyond these scientific measurements and observations, a suite of auxiliary data sets will be collected from the snow and ice team, mostly to complete meta data sets and complete the observational records:

- Time laps cameras of the central observatory
- Bridge observations of sea ice conditions
- Processing of ice cores and snow samples on site in the freezer lab on board Polarstern
- GPS referencing of all sampling sites and instrumentation of the central observatory

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; and internal sea ice stress. Repeated visits at selected nodes of the distributed network will allow complementary measurements, e.g. local transects.

Another important contribution, if this can be realized, is the use of an Autonomous Underwater Vehicle (AUV), which may be used occasionally to connect the central observatory with different autonomous nodes of the network. Key instrumentation for the sea ice team is an upward looking bathymetric multi-beam sonar to map sea ice bottom topography and spectral radiometers to characterize the spatial variability of the light climate under sea ice.

Observations from the hovercraft will help to extend transect measurements within the distributed network, as well as servicing autonomous stations and collecting surface samples, which are less impacted by Polarstern. Furthermore, the hovercraft will ease access to different sea ice / snow cover regimes for complementing measurements. This is of particular interest for measurements over new forming and rotten sea ice which may otherwise not be observed and sampled in a representative way.

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, as well as 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.

Observations during IOPs

During freeze-up and as a result of dynamic processes new ice formation and thin ice properties and processes will be observed with additional efforts compared to the baseline program. Similarly, sea ice dynamics and snow cover impacts of new deformation structures will be investigated in close collaboration with the ocean and atmosphere teams. During summer, melt processes of snow and sea ice and the evolution and properties of melt ponds are a key topic and will require intensified observations.

2.3 Ocean (team OCEAN)

To answer the research questions set out in the summary of the working areas we need to carry out the ocean observations detailed below. The general objectives are to understand heat and freshwater budgets, involving the following processes: changes in heat and freshwater inventories, large and mesoscale advection, vertical exchange across the halocline, the ice-ocean interface and the atmosphere-ocean interface in leads.

The system is forced from above by surface momentum fluxes, brine rejection or the addition of meltwater, and heat fluxes by conduction and visible light transmission. Important parameters to observe at different depths throughout the experiment: ocean currents, temperature and salinity, vertical stratification and shear, horizontal density gradients, eddies and internal waves and turbulence. This allows to quantify entrainment and mixing. Temporarily occurring processes, such as upwelling near the ice edge or vertical fluxes in the vicinity of leads will require additional observations. These will be carried out in different parts of the distributed network and beyond during IOPs.

Routine upper ocean profiling at the Central Observatory will form the basis of the experiment. Observations throughout the distributed network will encompass sub-mesoscale variability (eddies, internal waves, other boundary layer processes) and allow us to estimate how representative measurements at the central observatory are for the area covered by the experiment. This will help estimating the effect of processes below the size of typical model grid boxes in ocean general circulation models. The physical observations can also be used for estimating fluxes of biogeochemical and ecological variables.

Work on Polarstern

Weekly Conductivity Temperature Depth (CTD) / rosette profiles will be conducted throughout the expedition. This allows sampling for tracers and biogeochemical parameters, and will also support cross-calibration of sensors used across the MOSAiC constellation. The CTD/rosette will require a hole with a diameter of at least 2 m next to the ship. This could be maintained by a metal frame at the edge of the hole and hot air supply from the ship. Alternatively, the hole could be cut out of the ice before each weekly operation.

Acoustic Doppler Current Profilers (ADCP) will be operated continuously throughout the drift. As horizontal motion in the ocean varies on scales of a few meters to hundreds of meters, ADCPs with different frequencies will be used. Polarstern has a built-in ADCP (150 KHz, range from surface to about 200-300 m). A low frequency ADCP (38 KHz, range from surface up to 1000 m) could be mounted in the Polarstern moonpool. In addition, the Polarstern CTD/rosette is equipped with a lowered ADCP that can supplement the other ADCP observations or may be used as a backup for the 38 KHz ADCP.

Work on ice camp

Routine ocean observations from the ice camp will be made at/near a tent(s) installation called "Ocean City." One shallow CTD only profile (0-500 m) a day will allow to capture shorter-term variability in ocean temperature and salinity, and will also include sensors for measuring biological / chemical parameters. This routine profiling could be performed by a stand-alone CTD winch system, operated through a hole in the sea ice near the ship, or an autonomous profiling system (e.g. Ice-tethered Profiler; ITP) with CTD, oxygen, bio-optical Chlorophyll_*a* fluorescence and Colored Dissolved Organic Matter fluorescence / FDOM), and chemical sensors („CTD+"). If carried out manually, the daily profiles require a tent or hut around a permanent hole in the ice (approximately 50 cm diameter). If the hole next to the ship cannot be maintained and the ship CTD can, therefore, not operate, a smaller rosette needs to be used with a winch from the hut/tent. In that case, the hole may have to be bigger.

A high frequency ADCP (600 KHz or 300 KHz) will be mounted under the ice floe throughout the drift. This requires a cable link to the surface above the ice to allow data download and power supply to the instrument(s). A tent is required for this operation, especially during times of bad visibility and storms. If not mounted in the Polarstern moonpool, the low frequency ADCP (38 KHz) could be mounted alongside the 600 KHz device. Alternatively, there may be an AOFB, which includes a 300 KHz ADCP, deployed in the ice-camp.

Vertical profiles of turbulence will be measured weekly, resolving one inertial cycle, using a microstructure profiler (MSS). This will be followed by a profile of ocean optical properties (AC9, A-sphere). The manual, regular profiling requires a tent or hut around a permanent hole in the ice (approximately 50 cm diameter). In addition to temperature and shear microstructure, and a regular CTD, further sensors can be mounted on the MSS, e.g. Chl-a fluorescence, turbidity or dissolved oxygen. This could be the same hole as used for the daily CTD profiles. Depending on the sensors required in addition to the standard CTD the MSS may be used to provide the daily profiles.

Distributed network

Autonomous, buoy-based systems will be used to measure the following (upper) ocean state variables at multiple scales throughout the distributed network (see Section 3.3): temperature, salinity, dissolved oxygen, bio-optics, chemistry, velocity and turbulence. It is important to measure the ocean directly under the ice to support joint analysis of ocean and ice measurements. Additionally, at least one deeper ocean profiling station is needed within the Distributed Network. Ocean gliders will be used to provide horizontal linkages among the various ocean observing nodes in the Distributed Network. These gliders will require at least three positioning beacons to be installed across the network. This collection of ocean observing devices will need to be inter-calibrated and maintained on a routine basis or as needed.

Maintenance of the autonomous devices will require support by helicopter or hovercraft to move personnel and equipment within the distributed network. Buoy systems should be designed to survive at least two months during the dark winter period without servicing, as the helicopter may not operate during that time. All work should be supported by Polarstern crew where possible, e.g. electronic / mechanical engineers and workshops, in particular for the CTD/rosette.

Observations during IOPs

Processes in specific and opportunistic situations will be observed using more frequent profiles for time periods of one or two weeks. These include vertical fluxes and mixing in open leads during winter, and times of intense melt or freeze. Measurements could be carried out at a second ice-camp or at a location revisited daily by helicopter or hovercraft. The measurements with the devices already mentioned could be augmented by similar measurements from an Autonomous Underwater Vehicle (AUV).

2.4 Bio-geochemical System (team BGC)

The BGC-system includes all components (most trace gases) formed in the ocean-ice-atmosphere domains, which either migrate within one of the domains or move between the domains. The BGC-system is closely linked to the ecosystem. This coupling is especially relevant for the carbon, sulfur and nitrogen cycles.

Measurements within the BGC-system during the MOSAiC campaign need to be carried out at the central observatory on RV Polarstern, at the nearby ice camp, and at the distributed network of observing stations. The measurements cover a range of essential climate relevant trace gases and other components, which will need to be recorded continuously or regularly throughout the whole campaign. In addition, some dedicated measurements are foreseen for IOPs.

The main BGC topics in the coupled ocean-ice-snow-atmosphere system will be:

1. Sulfur cycle - sources and sinks of aerosols and aerosol precursors
2. Greenhouse and trace gases – pathways and fate
3. Halogen/mercury cycling in the coupled atmosphere-snow-ice-ocean system
4. Quantification of sea-air fluxes and precipitation by natural radionuclides

All measurements are needed to be linked to measurements in the atmosphere, sea ice, ocean and ecosystem.

Work on Polarstern

Weekly/bi-weekly water sampling (CTD/Rosette) will be conducted throughout the entire expedition. The ships laboratory space and room for lab-container is needed for installations of instruments like gas chromatographs, mass spectrometer radionuclide spectrometry and installation of autonomous underway system for measurements of our key parameters listed in the table included at the end (Table 9.4) in all compartments (ice, snow, water and air).

Work on ice camp

Most of the sea ice and snow sampling will be performed at the ice camp close to RV Polarstern. We envisage regular weekly/bi-weekly sampling of snow and sea ice (ice cores) to measure the trace gases. Ice and samples will be taken at the designated snow and sea ice sampling sites, jointly with the sea ice physics and ecosystems group to allow for integration all parameters from all discipline over time. We aim to do regular chamber measurements to determine the sea ice- air flux distributed over the entire ice flow. Sampling high resolution undisturbed under ice water profiles will be performed from the CTD hole in “Ocean City”. The large volume water samples for radionuclides will be retrieved from “Ocean City” hole using pumps.

Distributed network / Observations during IOPs

Some activities need to be made in some distance away from the ship to exclude its disturbance. This includes the flux measurements at the ice– atmosphere interface, snow sampling and under sea ice water sampling. Especially the melting during the spring summer transition and freezing events during autumn winter transition will be studied at a secondary ice camp in close collaboration with the ice team (ice physic and ecosystem group). Sampling and measurements in the distributed network will also serve to capture the spatial variability of our main parameters. This is of particular importance to develop budgets and estimates for model parametrization of the respective biogeochemical parameters and processes. This will helicopter or hovercraft support for transport of personnel, equipment and samples.

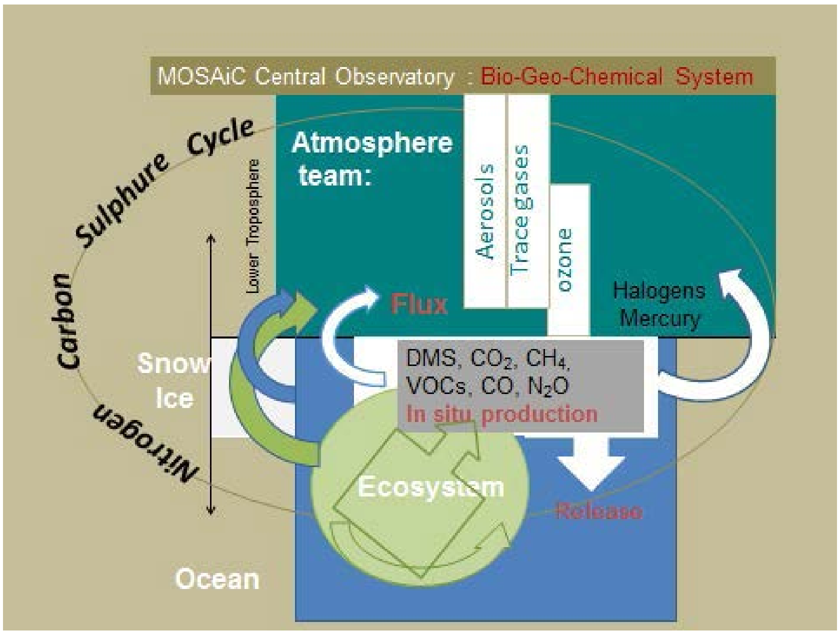


Fig. 2.3: Components for the measurements of the bio-geo-chemical system and links to atmospheric measurements (Figure: E. Damm).

At particular events, e.g. ice freeze-up and melt, opening of leads and thin ice formation, high biological activity in spring (for a full list see table… please include reference to event table) additional samples like slush, thin ice or frost flowers will be taken to complement the regular sample types. This will potentially require increasing the sampling frequency to capture these fast processes. Events/IOPs will be studied either at the central observatory or in the distributed network depending on the observed event location.

2.5 Ecosystem (team ECO)

Whereas the strong interdependency between the sea ice cycle and ocean-atmosphere physics is widely recognized, the tightly coupled interaction between sea ice and the biology and chemistry of the ocean underneath is not well understood and as a consequence, often neglected.

Biological activity however, not only affects the cycling and transformation of organic matter and elements, but also exhibits strong controls on the cycling of climate-active gases such as CO_2, CH_4, N_2O, and dimethyl sulfide (DMS) across the atmosphere-ice-ocean interfaces. The mobilization of nutrients and dissolved components, such as organic carbon and nitrogen, is strongly influenced by both convective and advective forces driven by the physically dynamic atmospheric, sea ice, and ocean systems. Ecosystem measurements require consideration of the strong links between these physical domains to elucidate how environmental conditions will impact and influence measured responses of the biological and chemical components CAO sympagic and pelagic communities during a complete annual cycle.

High-latitude ecosystems that use sea ice as substrate, habitat, and a foraging ground are highly productive and can respond relatively quickly to external changes in light, nutrient input, or grazing. However, the strength, timing, and net effects of these couplings on overall elemental and organic matter flow have not been established. To close this immense gap of knowledge, we plan detailed observations and measurements of biological controls on carbon and nutrient cycling, across sea ice and pelagic ecosystems. Special emphasis will be placed on measurements of functional biodiversity and physiological adaptations of primary producers and consumers of different trophic levels, such as copepods and fish.

Ecosystem objectives cover a diversity of interconnected topics, and as such are organized into 5 main themes in the coupled ocean-ice-atmosphere system:

1. Prokaryotes – diversity, abundance, and activity of single cell organisms, Bacteria and Archaea, and the roles they play in the transformation of climate-relevant compounds, organic matter, and nutrients
2. Protists – diversity, abundance, and activity of single cell microbes, such as phytoplankton, and the roles they play in primary productivity, food web dynamics, and organic matter production
3. Zooplankton and sea ice fauna – diversity, abundance, biomass, and activity of primary and secondary consumers, and the roles they play in structuring communities through grazing, predation, and life history in relation to elemental and organic matter cycling
4. Ecological chemistry – measurements of dissolved and particulate components of the sea ice and pelagic ecosystems to understand the standing stocks of photosynthetic biomass, concentrations and fluxes of nutrients and organic matter, characteristics of organic matter, and rates at which material is transformed.
5. Particle Dynamics and vertical fluxes – measurements of particle size spectra and vertical distributions in the pelagic system and measurements of organic matter flux from sea ice and upper ocean waters to below the halocline

Additionally, Ecosystems coordinates the sampling and analysis of ecological –omics samples spanning all system components, thereby producing a coherent, unified framework for MOSAiC - omics derived information from the atmosphere-snow/sea ice-ocean domains. The Eco –omics topic group develops the conceptual and implementation frameworks for all environmental and organismal DNA- and RNA-derived data sets.

Work on Polarstern

The Ecosystems team, in cooperation with the other MOSAiC teams, will conduct 1x weekly discrete sampling of Eco key parameters from sea ice and oceanic environmental matrixes. Sea ice, brine, and melt pond sampling will primarily occur in designated sea ice plots located within the Central Observatory. Water column sampling will primarily occur use of the main CTD-rosette package deployed from the Polarstern. Additional, upper 50 m sampling of the water column and direct under-ice water will be conducted from the Ocean City location on the main floe. Large plankton net sampling and LOKI profiles require ship-based mechanical support, and therefore must be conducted from the Polarstern to resolve higher trophic level contributions to biological, ecological, and chemical processes. Smaller ring nets will be used at Ocean City and potentially through the ship's moon pool, but are limited in their utility. However, due to the large volumes of water needed for key parameters, and additional cooperative perturbation/incubation experiments, the main rosette package equipped with large volume (12 L) Niskin bottles is essential. Large volume pumps will also be utilized to collect water samples.

General description of key parameter sampling and experimental work (please refer to Table 9.5):

1) Shipboard and sea ice sampling to resolve in/organic nutrient concentrations, and particle size spectra and concentration in vertical space using an Underwater Vision Profiler (UVP), 2) size-fractionated water samples for photosynthetic biomass (chlorophyll a; (Chl a) and bulk pigment biomarkers (High Performance Liquid Chromatorgraphy; HPLC), 3) bulk particulate organic carbon, nitrogen, phosphorus (POC, PON, POP) and Biogenic Silica (BSi) concentrations, and where appropriate, ^{13}C and ^{15}N elemental composition of POM, 4) primary productivity using both radiotracer and stable isotope approaches (^{14}C- and ^{13}C-bicarbonate assimilation rates), 5) Net community production (NCP) in surface oceanic waters via the O_2/Ar approach (MIMS), 6) Nitrogen (^{15}N-Nxx and ^{13}C-Cxx assimilation rate measurements 7) Eco -omics characterization of microbial diversity and activity, and larger biota, 8) net hauls, video-optical casts (LOKI), and continuous echosounding of zooplankton, and fishes. A series of large coordinated experiments to test for biological responses to light and nutrient perturbations will also be conducted by the Ecosystems team to address how biological communities respond and geochemical budgets are altered by changes to critical environmental components.

Work on Ice camp

Discrete snow, sea ice, brine, and melt pond sampling will occur 1x weekly for ecological key parameters, from as many as 1-5 different sea ice types. Sea ice cores will be sectioned and parameters to be measured are as dscribed above. Additionally, the ice camp provide important sites to execute under-ice light profile measurements throughout the year, especially during polar night, with limitation of artificial light contamination. We intend to limit the effects of artificial light contamination as is feasible during discrete sampling of sea ice and water during the polar night and other low light periods. Additionally, we will work with vertical nets, traps, under-ice cameras (acoustic and optical) and Acoustic Zooplankton and Fish Profilers (AFZP) to collect organisms from the ice underside and quantify their abundance and vertical movements.

Short-term sediment trap deployments at designated sites across the Central Observatory will allow us to measure the advection and sinking of particulate organic matter (POM) under the ice. Characterization of particles and aggregates could be achieved through underwater video profiling systems and particle analyzers as well as gel traps for the short-term sediment trap deployments. Experimental studies will assess particle formation and modification processes. Bio-optical sea ice buoys will be deployed in collaboration with the sea ice team to measure the evolution of bio-optical properties, biomass, and primary production between early spring and late autumn.

Distributed network

A small subset of sea ice and water column samples will aim to support the intercalibration of sensors across multiple DN sites and instrumented moorings/buoys. Sampling and measurements in the distributed network will also serve to capture the spatial variability of our main parameters. This is of particular importance to develop budgets and estimates for model parametrization, data assimilation, and model validation of biological interactions, and ecological and geochemical parameters and processes.

Observations during IOPs

Processes in specific and opportunistic situations will be observed using more frequent profiles for time periods of one or two weeks. These include vertical fluxes and mixing in open leads during winter, and times of intense melt or freeze. Sample collection and measurements will be carried out at a location revisited by helicopter or hovercraft. Sampling frequency and distribution will be coordinated with other MOSAiC teams for synoptic measurements of IOPs.

Methods for the Polarstern, Ice Camp, and Distributed Measurements, will include nutrient analyses for all macronutrients (nitrate, nitrite, phosphate, silicate and ammonium). This will be required on discrete samples, throughout the water column, and at the water / sea ice interface. Macronutrients will also be measured in melted sea ice samples, melt ponds and collected brine. Samples will also be generated from ship-board experiments and sensor calibration. A built- in KUNO-nutrient analyzer hooked up to the Polarstern ferry box will be used for continuous monitoring of surface nutrients. These will be complemented with nitrate sensors deployed on the CTD Rosette, at the distributed networks and mounted on gliders. Overall, special emphasis will be given to the nitrogen cycle, since nitrogen in oxidized and reduced form is critical for fueling new and regenerated primary production in the Arctic Ocean.

Autotrophic carbon uptake and oxygen release both from water column samples and sea ice cores will be measured in tracer experiments including size-fractionated $^{14}CO_2$ and $^{13}CO_2$ uptake rates, continuous O_2/Ar measurements as well as opportunistic Photosynthesis-vs.-irradiance assays to assess instantaneous potentials for productivity. This will generate temporally resolved estimates of annual net primary production, and yield data on the partitioning and/or coupling between sea ice and pelagic biomes. Bacterial productivity in bottom sea ice and pelagic waters will be assessed using ^{3}H-Leucine/Thymidine incorporation measurements. Abundance of bacteria, phytoplankton, and zooplankton, as well as their species distribution will be addressed through flow cytometry, image recognition strategies (Imaging Flow Cytobot), and light microscopic analyses of discrete samples from sea ice and sea water. Nucleic acids collections (DNA and RNA) in combination with a variety of molecular ecological approaches will be used to study the diversity, abundance, and activity of single cell prokaryotes and protists in sea ice and water samples mainly at the central observatory. Sea ice and water samples will be processed for measurements of plankton biomass (POC, PON, POP, BSiChl a, pigment biomarkers). POC and PON measurements will also yield ^{13}C and ^{15}N natural abundance data. Organic matter cycling will be assessed by a number of measures including various measurements of DOC, DOM, transparent exopolymer particles (TEP), and particle size spectra. Food web structure will be identified using a combination of stable isotope approaches and genetic markers, which will include the analysis of sea ice derived POM, pelagic POM, major zooplankton taxa, and sinking material from sediment traps.

Organic matter and nutrient fluxes driven by grazers will be addressed, from microzooplankton to polar cod via estimates of organisms´ abundances and physiological states. This also involves grazing experiments. Animals will be collected by regular rosette sampling for small zooplankton and by multi-net sampling and pumps for larger and under ice species. Hydroacoustics will be used to monitor vertical migration and mesoscale spatial variability off zooplankton and small fish, including under-ice moorings at the distributed networks.

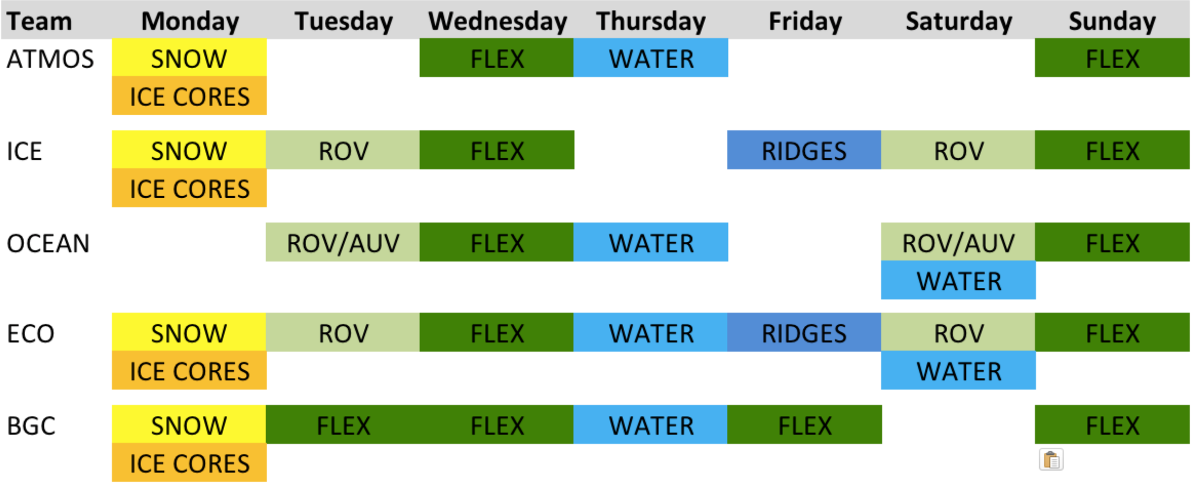
2.6 Cross-team coordination

Weekly schedules

All common activities are coordinated across the five teams will be organized according to a fixed weekly schedule. This will optimize the scientific merit of the data sets, but also be most efficient in field work logistics (equipment, groups on the ice, etc.). The core elements of these weekly schedules are summarized in Figure 2.4, where all cross-coordinated activities are assigned to a specific weekday, e.g. ice coring and snow sampling will be performed on Mondays. Many of these activities have complex dependencies with other activities of the different teams for the coming days and weeks, e.g. processing of samples and links to experiments. In addition, ‘flex time’ is accounted in all teams. This flex time allows to 1) perform additional and individual projects, 2) react on ‘events’ (see below), and 3) compensate for missed observations, e.g. due to weather conditions.

The weekly plans will change over the seasons due to different foci over the year. Some measurements, e.g. melt pond studies, will only be performed during parts of the year and most measurements will vary in intensity over the year, e.g. are more labor intensive in darkness and cold or changes are expected to happen more rapidly during transition phases. The step from one weekly plan to the next will be defined through natural events (e.g. melt onset) and will finally be decided by the science board on board Polarstern (see Section 4.4).

Beyond the main time series and regular observations, ‘event’-driven observations and work will be an essential part of the field measurements. The occurrence of an event will interrupt the weekly schedule of some or all teams, because they need to adapt their observational program to the event. For example, the opening of a new lead close to Polarstern will impact the work of all teams, because it impacts the exchange of momentum, energy, and mass between atmosphere, ice and ocean. A significant part, but not all, measurements will focus on this lead on the following days or weeks. The list and definition of events and their impacts on the individual team program is currently under discussion. The criteria, e.g. thresholds of wind speeds that define a storm event, need to be well defined, because it is important to balance the total number of events in order to maintain both, the general time series and the more intensive observations. More details on selected events and how related processes will be studied during MOSAiC are described in Section 3.8.



Team	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
ATMOS	SNOW		FLEX	WATER			FLEX
	ICE CORES						
ICE	SNOW	ROV	FLEX		RIDGES	ROV	FLEX
	ICE CORES						
OCEAN		ROV/AUV	FLEX	WATER		ROV/AUV	FLEX
						WATER	
ECO	SNOW	ROV	FLEX	WATER	RIDGES	ROV	FLEX
	ICE CORES					WATER	
BGC	SNOW	FLEX	FLEX	WATER	FLEX		FLEX
	ICE CORES						

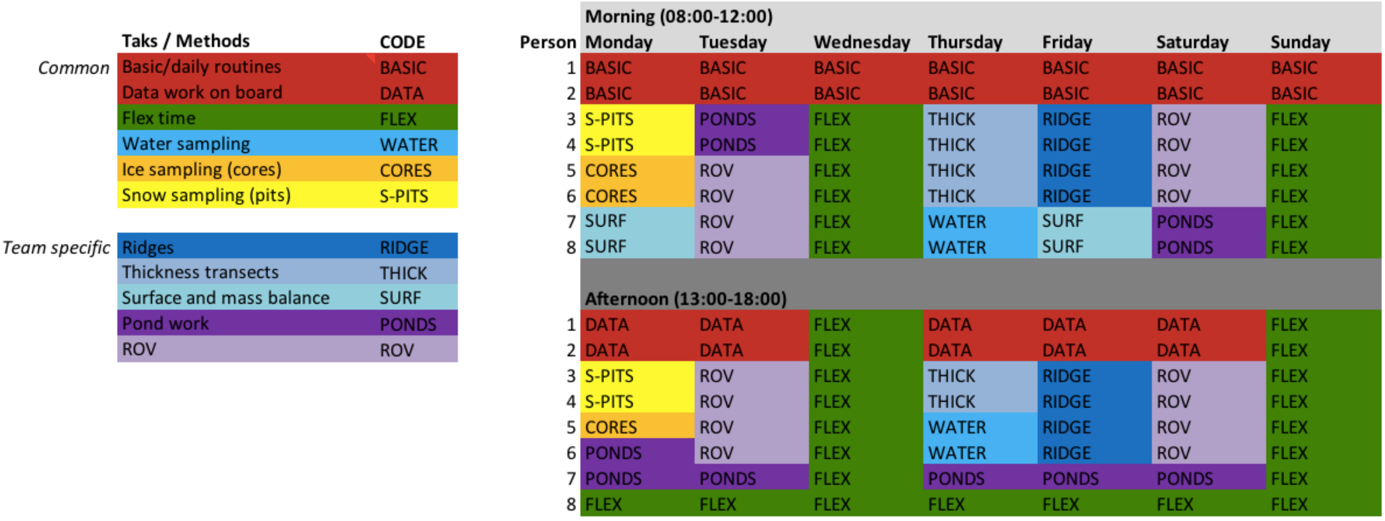
Fig. 2.4: Weekly schedule of all main cross-cutting activities. SNOW: Snow pits and snow sampling, ICE CORES: Ice coring, ROV and AUV: ROV and AUV work, WATER: Water sampling and main water column work, RIDGES: Pressure ridge measurements, FLEX: Flexible time for each team (see flex-time concept). An exemplary schedule for one team is shown in Figure 2.5.

In addition to the coordination across all teams, Figure 2.5 shows an example of a weekly plan for one team. Each team will allocate personnel and time for its individual tasks at a fixed time during the week (see Figure 2.5) and also contribute to the common activities. Some teams have significantly higher fractions of daily routines (mainly team ATMOS), while others need more flexible time in order to embed specific experiments (mainly team ECO).

Coordinated sampling

Sampling programs of snow, sea ice, and water are coordinated across all teams in order to optimize the scientific output as well as the resources of obtaining the sampling and processing the samples. It was agreed that the sampling strategy is coordinated by different teams:

- Snow by team ICE
- Sea ice by team ECO
- Water by team OCEAN



	Taks / Methods	CODE
Common	Basic/daily routines	BASIC
	Data work on board	DATA
	Flex time	FLEX
	Water sampling	WATER
	Ice sampling (cores)	CORES
	Snow sampling (pits)	S-PITS
Team specific	Ridges	RIDGE
	Thickness transects	THICK
	Surface and mass balance	SURF
	Pond work	PONDS
	ROV	ROV

	Morning (08:00-12:00)						
Person	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	BASIC	BASIC	BASIC	BASIC	BASIC	BASIC	BASIC
2	BASIC	BASIC	BASIC	BASIC	BASIC	BASIC	BASIC
3	S-PITS	PONDS	FLEX	THICK	RIDGE	ROV	FLEX
4	S-PITS	PONDS	FLEX	THICK	RIDGE	ROV	FLEX
5	CORES	ROV	FLEX	THICK	RIDGE	ROV	FLEX
6	CORES	ROV	FLEX	THICK	RIDGE	ROV	FLEX
7	SURF	ROV	FLEX	WATER	SURF	PONDS	FLEX
8	SURF	ROV	FLEX	WATER	SURF	PONDS	FLEX
	Afternoon (13:00-18:00)						
1	DATA	DATA	FLEX	DATA	DATA	DATA	FLEX
2	DATA	DATA	FLEX	DATA	DATA	DATA	FLEX
3	S-PITS	ROV	FLEX	THICK	RIDGE	ROV	FLEX
4	S-PITS	ROV	FLEX	THICK	RIDGE	ROV	FLEX
5	CORES	ROV	FLEX	WATER	RIDGE	ROV	FLEX
6	PONDS	ROV	FLEX	WATER	RIDGE	ROV	FLEX
7	PONDS	PONDS	FLEX	PONDS	PONDS	PONDS	FLEX
8	FLEX	FLEX	FLEX	FLEX	FLEX	FLEX	FLEX

Fig. 2.5: Example of a weekly schedule for one leg for one team of 8 persons. Note: This example only illustrates the principle not any real schedule. Further note that e.g. Person 3 on Monday is not necessarily the same individual as Person 3 on Tuesday.

3. OBSERVATIONAL SCALE AND SCIENTIFIC-TECHNICAL IMPLEMENTATION

One of the foundational concepts for MOSAiC is the need to characterize the spatial variability of key system properties and processes. To accomplish this objective, the required measurements outlined in Section 2 will be implemented across multiple scales at MOSAiC.

3.1 Installations, Labs, and Containers on Polarstern

The German research icebreaker Polarstern (Figures 3.1, 3.2, 3.3, 3.4) will be the home of all MOSAiC participants during the drift. Besides being the living and working platform, Polarstern serves various other needs, which make it the key element of MOSAiC:

- Almost all laboratories, workshops, and offices are on board
- Many installations on board on almost all decks will help to observe the environment
- All lab and observational containers will be installed on the vessel
- Continuous measurements will be performed through existing under-way instrumentation
- It is an observational platform from the bridge and the crow’s nest
- All main winch systems are installed on and are operated from the vessel
- The helicopter deck will serve as hub for the flight operations
- Sample and cargo storage

However, it has also to be noted that the vessel itself has a large impact on the environment (see Section 4.8). This section describes the necessary preparations and realizations on the vessel in order to enable the various measurement programs of all teams (Sections 2.1 to 2.5).

Preparations before the drift

The winterizing and the continuous observational program through the entire winter will require some particular preparations before departure to MOSAiC. Additional modifications may also be needed to support the necessary instrumentation. These preparations will be performed in close cooperation between the MOSAiC teams, the AWI logistics, and the ship operator Laeisz. Currently the following aspects are considered:

- Re-installation of Polarstern bow tower: This will allow for the installation of meteorological and flux instrumentation towards the bow of Polarstern to enable continuous measurements for the full MOSAiC period. (see Figure 3.1)
- The main CTD winch needs a cover that allows the operation of the winch and access to the ocean through the entire winter. This cover will help to maintain open water or easily removed ice.
- The illumination of working areas on the ice has to be discussed, also including the aspect of light pollution during darkness.
- The Moonpool of Polarstern may be modified in order to allow some winch operations (casts, sampling) through it, in particular during winter, when it might be difficult to maintain an ice hole close to Polarstern.
- Preparations for installations of sensors and antennas on board, including power and data connections.
- The ice gangway concept

Fig. 3.1: Polarstern with bow crane. This is an archive photo, because the crane is currently not installed, but is planned for MOSAiC again. Here the Sea Ice Measurement System (SIMS) is installed hanging in front of the bow. In the background the ice gangway is installed on port side. (Photo: AWI)

Laboratory arrangements during the drift

Polarstern provides a suite of laboratories, workshops, and offices to accommodate most needs of the different teams. Additional workshops, labs, and storage space will be brought on board in the form of containers (see below). Most rooms are on E-Deck and all rooms and areas are outlined and labelled in Figure 3.5. Discussions on the use and responsibility of the different facilities are ongoing, but have not yet been agreed. This plan is based on good experience from interdisciplinary expeditions and their use of ship space, but will also consider the particular requirements of long-term observations for MOSAiC. A large wet lab on E-deck will be used for all teams, e.g. for staging field equipment and other logistical needs. Dry labs will be distributed to the different groups, aiming for consistency over all legs. Chemical and biological labs, as well as an isotope container are available through the entire experiment.

All electronic data processing, storage, and exchange will make use of the existing network and server infrastructure on board. This infrastructure also allows direct access to a large suite of sensor data (atmosphere, ocean, position) of Polarstern. Additional computer and sensor systems will be added to the existing systems. Data exchange (e-mail, real time observations, satellite data) will be arranged (mostly) through Iridium connection (128 kbit).

Container arrangements on board Polarstern

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. Depending on their usage, all containers have different requirements in terms of power and water supply as well as temperature. Containers E1 to E10 and all F-Deck containers are indoors, while all other containers are stored and operated outside. Containers F11 to F14 have very limited access through a narrow stair case. Here we distinguish the following container types:

- “Lab” containers need electrical power
- “WetLab” containers need electrical power and water (in/out)
- “FreezerLab” needs electrical power and temperature control
- “Storage” containers have no special requirements
- “Storage temp” containers need electrical power for basic temperature adjustments

Fig. 3.2: Photo of Polarstern in sea ice with a helicopter taking of for a measurement survey. Letters name the decks on board: E-Deck includes the working deck in the aft, D-Deck is the bottommost white deck, C-Deck hosts the helicopter platform, A-Deck is directly under the bridge, and P-Deck (German: Peildeck) on top of the bridge with the Observation (Obs) deck behind it and some steps lower. The Crow's nest (Crow) is the highest observational platform.

More details of all containers as currently planned are available from Figure 3.5 and Table 3.1. However, a major uncertainty is still the amount of total freight and how many containers will be needed to accommodate the scientific cargo.

Installations on board Polarstern

Beyond installations in laboratories in the ship, antennas, cameras, and other devices and experiments will be installed on suitable positions outside on Polarstern. Most prominent are opportunities to use the crow's nest for installations that require a view of the sky or access to higher altitudes. Current plans include the installation of (see Figure 3.2 for deck names):

- Wind LIDAR on observation deck (Obs)
- EMIRAD remote sensing antenna on observation deck (Obs)
- Thermal imager (FIRST) on crow's nest (Crow)
- Various meteorological instruments along most of the reeling on P-Deck
- Incubation experiments on the working deck in the aft (E-Deck)

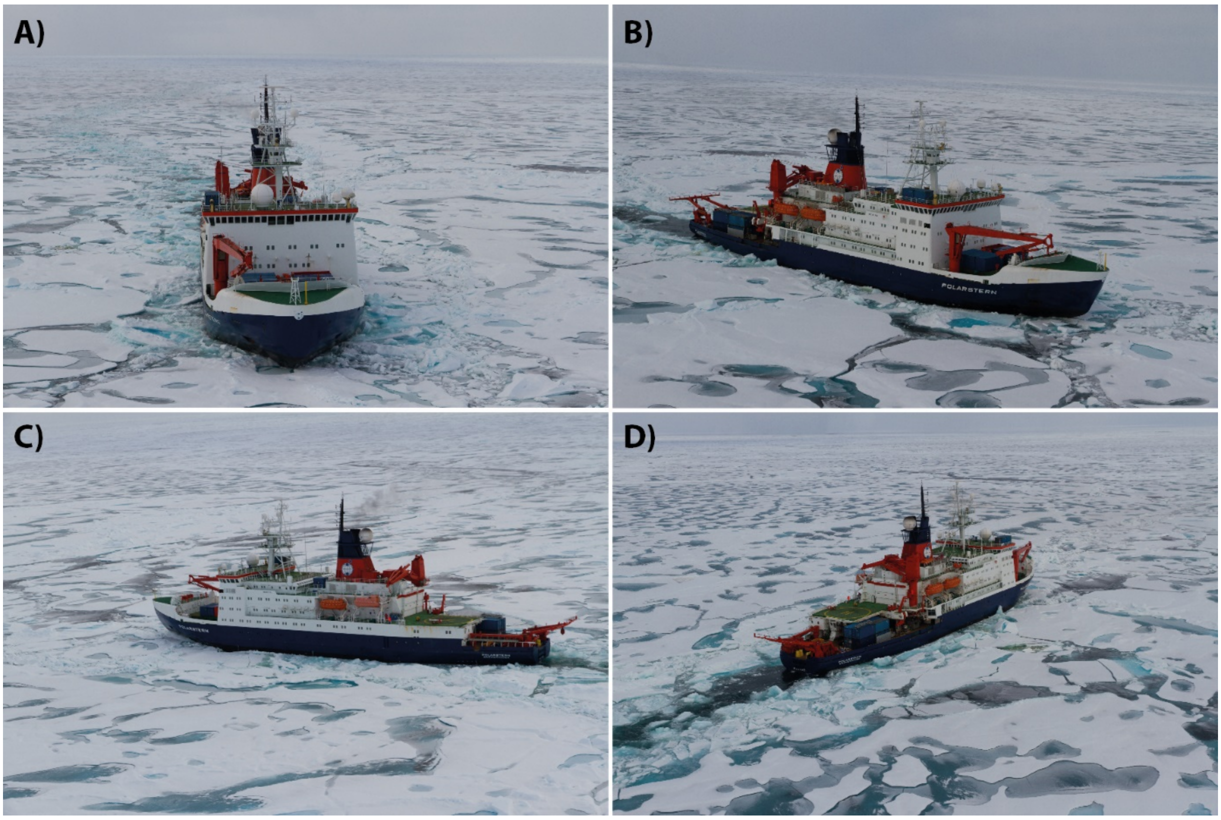


Fig. 3.3: Photos of Polarstern in sea ice from different perspectives. The photos illustrate the different decks, cranes, and possibilities for installation and storage. (Photos: M. Nicolaus).

Fig. 3.4: Nadir photo of Polarstern on an ice edge. This image might help illustrate the positions of containers and installations on deck. In this case 7 containers (20“) are carried on the bow and two smaller containers on the P-Deck (see also description in Figure 3.1). (Photo: S. Hendricks)

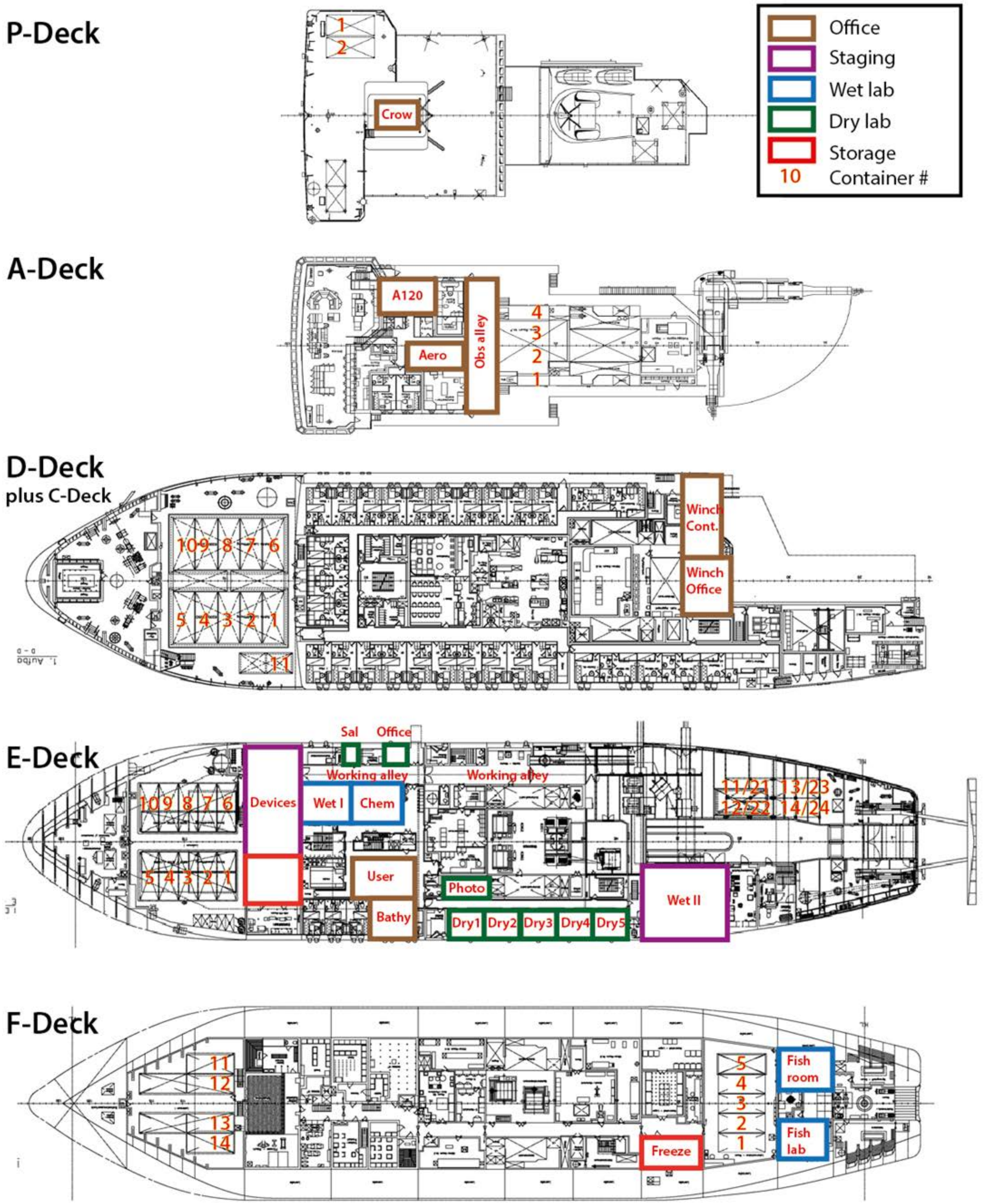


Fig. 3.5: Positions of containers, laboratories and offices on the different decks of Polarstern. “Offices” may also include computers and electronics in a wider sense (e.g. registration units or instruments). Deck names refer to Figure 3.1, containers are numbered as used in Table 3.1.

TABLE 3.1: Current container configuration with indication of container usage. Container types are described in the text. The Radar is no container as such, but requires one container spot. Abbreviations: T: Temperature, Tout: Outside temperature (=no temperature control), Tin: ship temperature. Letters and numbers indicate the position on board as shown in Figure 3.5.

#	Usage	Institute (PI)	Type	Comment
P-Deck				
P1	ARM-SACR	DOE (Shupe)	Lab	17000lbs, max 7t
P2	ARM-SACR	DOE (Shupe)	Radar antenna	Scanning radar
A-Deck				
A1	FTIR	Uni Bremen	Lab	10” container, T=Tout
A2	Helicopter	Polarstern	Storage	10” container, T=Tout
A3	Ship supply	Polarstern	Storage	10” container, T=Tout
A4	Ship supply	Polarstern	Storage	10” container, T=Tout
C-Deck (on top of D-Deck containers)				
C1	Planes/Hovercraft	???	Storage	T=Tout
C2	Container sled	AWI Logistics	unpacked	
C3	ARM-OPS	DOE (Shupe)	Lab	Vertical view
C4	ARM-KAZR	DOE (Shupe)	Lab	Vertical view
C5	ARM-AOS	DOE (Shupe)	Lab	Needs adjacent open space
C6				
C7	Container sled	AWI Logistics	unpacked	
C8	OceanNet	TROPOS	Lab	Vertical view
C9	Aerosol	PSI (Schmale) / BAS	Lab	
C10	ARM-MAOS	DOE (Shupe)	Lab	Needs adjacent open space
D-Deck Bow outside				
D1	Science equipment	AWI Logistics	Storage	T=Tout
D2	Science equipment	AWI Logistics	Storage	T=Tout
D3	Science equipment	AWI Logistics	Storage	T=Tout
D4	Science equipment	AWI Logistics	Storage	T=Tout
D5	Science equipment	AWI Logistics	Storage	T=Tout
D6	ARM-GP	DOE (Shupe)	Lab	
D7	Flux	CU (Shupe)	Lab	
D8	Samples	AWI Logistics	Reefer	T=+5C
D9	Samples	AWI Logistics	Reefer	T=-20C
D10	Science equipment	DOE (Shupe)	Lab	T=>0°C
D11	Fuel container (DG)	Polarstern	Storage	
E-Deck Bow inside				
E1	Workshop Ozean	AWI (Rabe)	Lab	
E2	Freezer lab	AWI (Nicolaus)	Reefer	T=-20C
E3	Workshop HEM/ROV	AWI (Nicolaus)	Lab	
E4	Science equipment	AWI Logistics	Storage	T=Tin
E5	Science equipment	AWI Logistics	Storage	T=Tin
E6	DMS	U Groningen	WetLab	Temp controlled
E7	Radionuclides	AWI	Lab	T=Tin
E8	ECO filtration	AWI	Wetlab	???
E9	BGC/ECO lab	AWI	WetLab	

E10	Science equipment	AWI Logistics	Storage	T=Tin
E-Deck Working deck				
E11	Basic warm lab	AWI Logistics	Reefer	T>0°C
E12	Basic cold lab	AWI Logistics	Lab	T=Tout
E13	Scooters/sleds	AWI Logistics	Storage	T=Tout
E14	Scooters/sleds	AWI Logistics	Storage	T=Tout
Over E11	Logistics (garbage)	AWI Logistics	Storage	T=Tout
Over E12	Logistics (boxes)	AWI	Storage	T=Tout
Over E13	Logistics (ice camp)	AWI	Storage	T=Tout
Over E14	Logistics (ice camp)	AWI	Storage	T=Tout
F-Deck (aft, special size containers only)				
F1	Radio isotopes	AWI	WetLab	Radio isotope container
F2	Photophysiology and PP	AWI	WetLab	
F3	C, N Stable isotopes	AWI	WetLab	
F4	Zooplankton	AWI	WetLab	
F5	Eco Sea Ice processing	AWI	WetLab	T=+4C
F-Deck (bow, limited access from E-Deck)				
F11	Clothing	AWI Logistics	Storage	
F12	Food	AWI Logistics	Reefer	
F13	Samples -20C	AWI Logistics	Reefer	
F14	** empty **			

3.2 Major Installations on/in/under the Ice Camp

Description of the main camp

The main ice camp builds together with Polarstern the Central Observatory (Figure 3.6). It is accessible through a gangway whenever needed. The area directly adjacent to the vessel will be used for logistics, tests, preparations, and leisure time. A system of defined walk and drive ways will be established using flags connecting the different measurement sites. The main "highway" will contain a power line of 500m length, connecting the main measurement sites (cities) to Polarstern. The power line system will require routine oversight and maintenance to ensure robust power to the ice camp facilities. Main sites will make use of the installation of semi-permanent huts on the ice as a base of operations and shelter for personnel. In addition, designated observation sites and "sanctuaries" (no walk, no drive, no drilling, etc.) will be defined to allow full annual observations with minimal impacts from previous observations and movements. The camp will be based on a culture of walking: Snow scooters will be used for transportation of equipment, but not for general travel of personnel on the ice. In addition, snow scooters will be important to support polar bear safety and possible recovery of instruments, installations, or personnel.

Installations in the main "cities"

- Met City
    - Met City will be at the farthest end of the ice camp away from Polarstern. Most other camp activities will be along the line connecting Met City back to the ship to help ensure a minimum sector of impacts from objects on the sea ice.
    * 1-2 huts for electronics controlling the continuous measurements
    - Nearby Permanent installations
        - 15 and 30m weather masts for meteorology, energy flux, and gas flux measurements

        - Radiation station: long-wave and short-wave radiation
        - Precipitation station: multiple precipitation measurements
        - Wind measurements: Sodar and wind profiling lidar
    - Tethered balloon operation tent
    - * UAV operations hut (possibly mobile) to support UAV deployments. This may utilize the tethered balloon tent.
    - * Temporary installations will be made at numerous locations on the sea ice for sampling aerosols and chamber gas fluxes.
    - No walk areas will be established around some of the key measurement sites (i.e. radiation) and a No structure area will be established beyond the met tower installations.
- Ocean City (min. 300 m away from ship)
    - 2 huts for electronics controlling the continuous measurements
    - 1 hut with open water access underneath for casts (down to 1000m)
    - Permanent installations
        - Under-ice flux measurements
        - Ocean velocity profiles (ADCP)
        - CTD chains and/or CTD profilers (with BGC and flux sensors)
        - Under-ice BGC sensors
- Ice City
    - 2 huts with open water access close by for ROV operations, eventually portable system to cover different access points
    - Survey lines for snow and ice parameters, including albedo transect (e.g. triangles with 1km perimeter)
    - Scattered sampling and measurement sites of different snow and ice conditions
        - Snow pits, ice cores
        - Ridges
- Bio villages
    - Defined sampling and experiment sites
- General logistics
    - 2 huts for shelter at different places

Large instruments

- Airboat (hovercraft) for movement around the ship, also on thin (new or melting) sea ice. This vehicle could also be used to reach nodes of the distributed network when helicopter flights are not possible.
- ROV for scientific missions and visual inspection of under-ice installations and conditions
- AUVsfor scientific missions / need to discuss recovery scenarios in closed ice cover, use under ice acoustic navigation array.

Runway

Starting in March 2020, and depending on flight operation details, it is planned to prepare a runway 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. The position will depend on local ice conditions, but a distance of <3km to the ship is the goal. Runway preparation will be performed by plowing and leveling the snow/ice surface using a Pistenbully.

3.3 Deployment and Operation of the Distributed Network

A distributed network of autonomous and semi-autonomous sensors will be installed around the Central Observatory to measure spatial heterogeneity and variability of key parameters on model grid-box scales of up to 40km (Figure 3.7 and Figure 3.8). This distributed network will be comprised of multiple sets of stations that contain distinct instrument

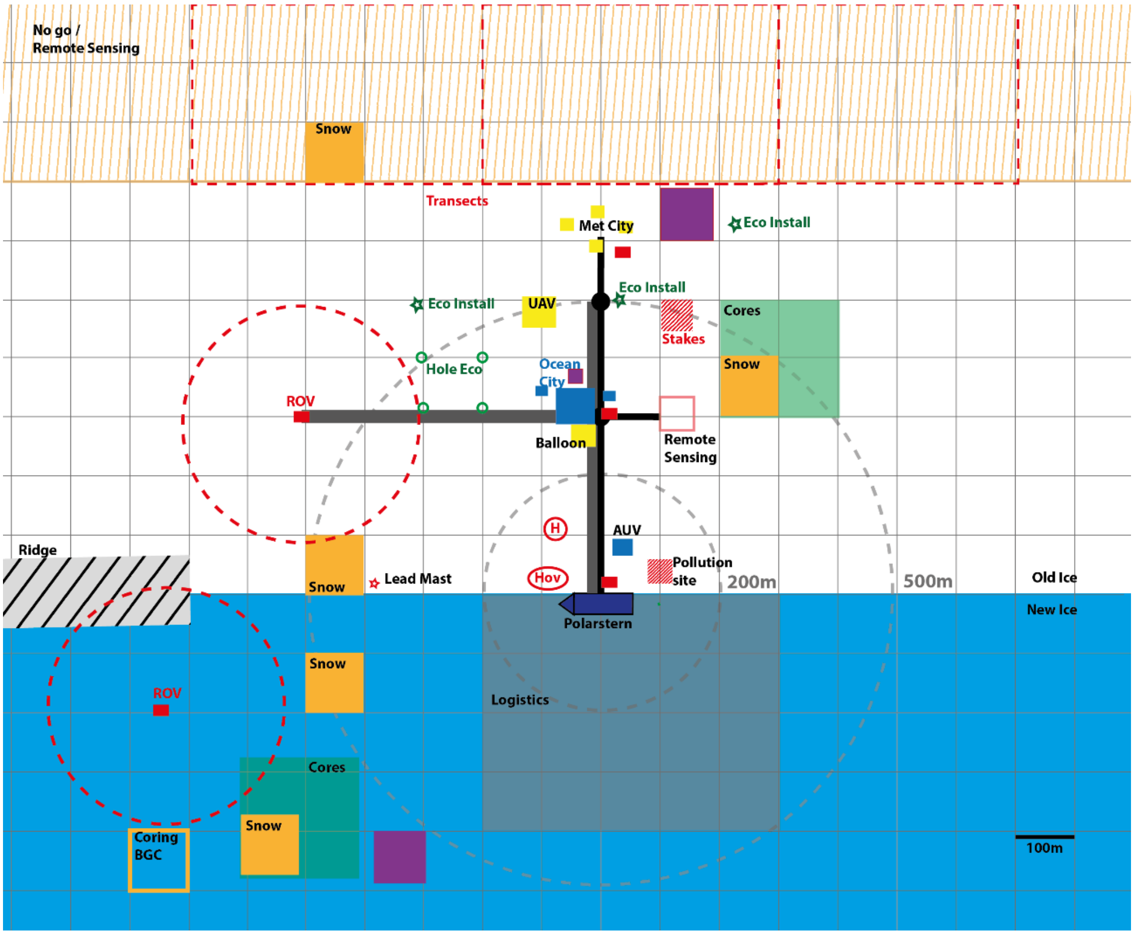


Fig. 3.6: Schematic of the different installations on the ice camp at the Central Observatory.

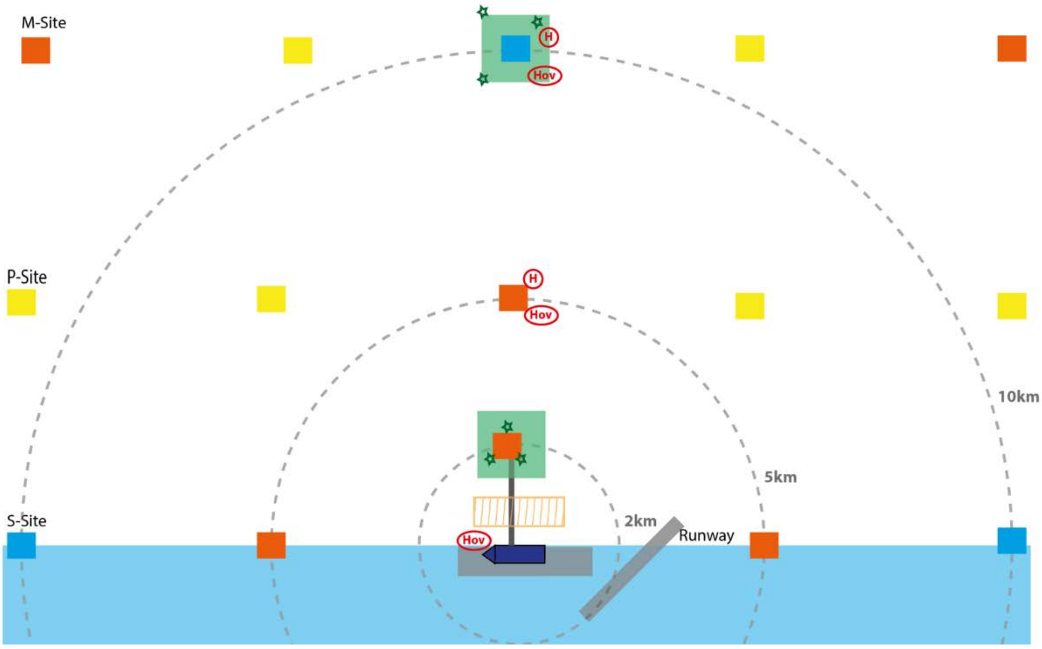


Fig. 3.7: Illustration of the transition from the Central Observatory into the Distributed Network (see Figure 3.8). It is planned to define a few remote sites in distances of 2, 5, and 10 km from Polarstern that are regularly re-visited during the drift. These sites will contain autonomous installations, but also those that need regular maintenance. In addition, sampling of snow, ice, water, and air in a distance from Polarstern will be enabled.

suites to be deployed on distinct scales (see Figure 3.7 and Figure 3.8). The primary station types are described in Table 3.2. The more complex supersites will include comprehensive, interdisciplinary measurements distributed approximately 10-15km apart at install. Medium sized sites will include primarily upper ocean and ice measurements over a denser network with 2-5km spacing. Position will be measured at all sites, including at simple sites with only position buoys, to provide a dense network for examining sea ice deformation and drift and multiple scales out to 40km distant from the Central Observatory.

Deployment and re-deployment

Most of the components of the distributed network will be deployed during the general MOSAiC installation period in early October 2019; a preliminary spatial map of network stations is given in Figure 3.8. First, the location for the Central Observatory will be determined and marked. Thereafter, the distributed network will be deployed using other support vessel(s) including the AARI vessel Tryoshnikov. The focus at this initial deployment stage will be on the major installations, specifically the three Supersites as these include buoys that are not well-suited to deployment without a ship. Smaller network stations will be deployed in parallel and during the following days from the Central Observatory using helicopter, skidoo and (if available) hovercraft support.

Over the course of the year-long drift the status and location of all network stations will be monitored. If the spacing and location of stations becomes less functional for meeting MOSAiC scientific needs (i.e., stations drifting too far apart, or stations falling offline), there will be the potential for recovering and/or re-deploying stations, likely in spring of 2020. If necessary these re-deployments will be conducted using helicopter and (if available) the hovercraft, but they may also be assisted by re-supply vessels if appropriate. There is also the potential to reserve some resources for later deployment in spring of 2020 or at other times during the year.

Operations

The general expectation is that distributed network stations will be largely autonomous; most of the buoy-based technologies envisioned for these stations are routinely operated in this fashion. However, given the opportunity afforded by having a manned drift station, and in order to ensure the best possible measurements, some stations may be visited for maintenance. Some stations, such as the Atmospheric Surface Flux Stations (ASFS), must be visited on a routine basis. Additionally, manual measurements for BGC and biology will be made at some of these remote stations. Station visits will be conducted primarily with helicopter, subject to flight restrictions. The target will be to visit ASFS stations once per month. BGC/biological sampling will occur. Station visits could also be supported via hovercraft, airboats, or potentially snow machines when ice conditions permit.

Since data will typically be transmitted from these remote stations via satellite communications, operational information regarding the location of network assets, their data quality, and other details will be monitored by the appropriate investigators. This information will be communicated to the appropriate science team coordinator(s) on a routine basis to support decision making and network support.

Lastly, remote stations will be used as waypoints for operations by autonomous oceanic and atmospheric platforms. Such measurements will help with linking observations made at the different network nodes with the Central Observatory.

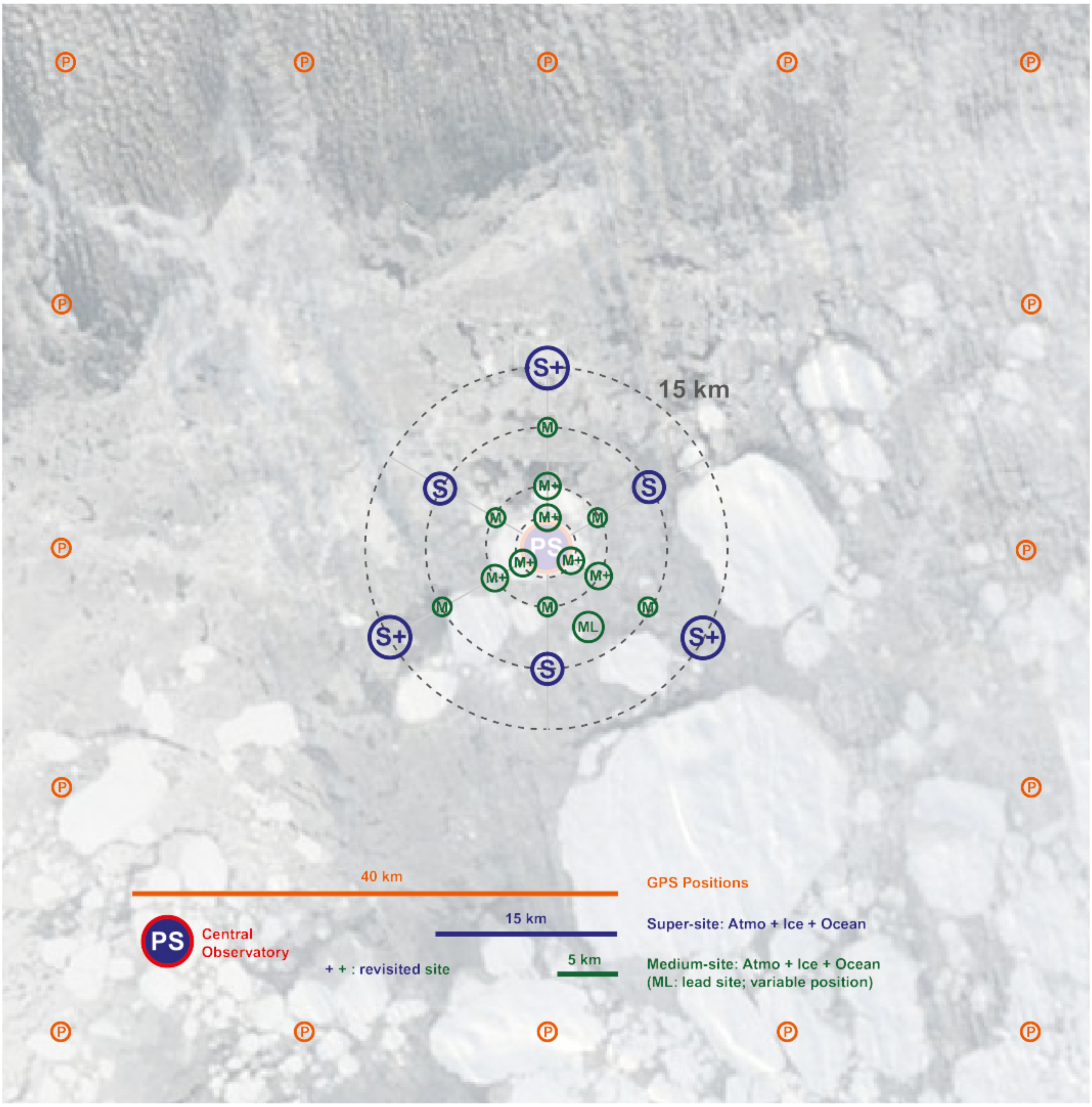


Fig. 3.8: The distributed network is arranged around the central observatory with Polarstern (PS) in the middle. It covers several additional scales: 2, 5, 15, and >20 km. Different colors and letters refer to the list of autonomous devices (see Table 3.2). The schematics is drawn to scale on a MODIS satellite image at approx. 84°N / 140°E on 29 Sep 2017. This illustrates a realistic ice condition for a potential start position of the drift (Figure: B. Rabe & M. Nicolaus (AWI))

Inter-calibration

An important aspect of the distributed observations is the cross-calibration of different platforms carrying similar sensors. One way to facilitate this is using the glider measurements and comparison of profile observations in ocean layers deeper than the halocline (autonomous CTD+, CTD+/rosette from ship with sampling, turbulence profiler with CTD+). A complete cross-calibration should be completed monthly.

TABLE 3.2: Distributed Network station types. Included is a list of the specific buoys and/or measurement packages that will be included at each station type. The spatial distribution of these stations is shown in Figure 3.7 and Figure 3.8. Specific platforms are described in more detail in Table 3.3.

Station Type	**Platforms, with measurements (one of more sites of station type)**	**Comment**
Large site (L1 - L3)	Upper ocean deep profiler (depth range: 5 m to 300/60/800 m), Ice-mass .air chemistry, under-ice and halocline turbulent fluxes and microprofiles, acoustic backscatter (single freq.), horizontal ocean velocity (surface to 80 m), in-/under-ice radiation, in-/under-ice biooptics and -chemistry, spectral surface and under-ice radiation, snow thickness, spectral surface radiation, above-ice turbulent and radiative fluxes, surface meteorology, cloud observations, passive acoustics, acoustic tomography, high-resolution GPS	Sites to be revisited for servicing / calibration / auxiliary measurements; L1 site closest to PS (10 km), L2-3 15 km away. L1 should be reachable year-round, even during darkness (combination of skidoo and heli operations; supported by hovercraft, if available.
Medium site (M)	Upper ocean states and optics, surface meteorology, upper ocean profilers (depth range: 5 m to about 100 m), passive acoustics, ice-mass balance, snow thickness, High-resolution GPS	Measurements / buoy types at these sites will vary. M-sites will be split into 2-3 categories in the future. Most of these sites do not have to be revisited on a regular basis but may be if the opportunity arises.
Medium lead site (ML)	Various in-situ measurements; seleted buoys for later autonomous measurements	Site will be chosen by opportunity / ease of access and may be revisited.
Position site (P)	GPS / position (variable resolution)	The location of position sites in the map of the Distributed Network are only exemplary. There will be a multitude of position sites at different scales in the Distributed Network.
Mobile / throughout	Ocean- or ice-observing AUV (operating in optimized pattern between sites L and PS / ice-camp)	Excact types of AUV not, yet, clear: for under-ice and ocean measurements

TABLE 3.3: Platforms and measurements for the distributed network.

Name of Buoy / Platform	**Measurements**
Ocean profiling systems	Ocean profiles of temperature/salinity/pressure, Chl-a and CDOM fluorescence, optical backscatter, nitrate , pH, dissolved oxygen, PAR, turbulence and velocity
Ice-mass balance	Sea ice thickness, snow depth, air/snow/ice T profile, visual imagery, position
Snow thickness	Acoustically measured snow thickness
Spectral surface and unde-rice radiation	Spectrally resolved surface atmospheric and under-ice radiative fluxes
In-/under-ice biooptics and -chemistry	Solar flux, nitrates, Chl a and CDOM fluorescence, dissolved oxygen, optical backscatter / turbidity
In-ice spectral radiation profiles	Spectrally resolved radiation profiles in ice
Under-ice and halocline turbulent fluxes and microprofilers	Turbulence (momentum, heat and salt fluxes) and microstructure of the under-ice boundary layer and in the pycnocline (e.g. around 50 m)
Acoustic backscatter	Single or multiple frequency acoustic backscatter
Ocean velocity	Profiles or point measurements of horizontal ocean velocity
Upper ocean state and optics	Upper ocean chains for temperature, salinity, pressure and radiation
Above-ice turbulent and radiative fluxes	Surface atmospheric broadband radiative fluxes, turbulent heat fluxes
Surface meteorology	Surface atmospheric pressure, temperature, wind, relative humidity
Cloud observations	LIDAR observations of cloud presence
Acoustic tomography	Acoustic receivers / transmitters to measure ocean state over large distances
Passive acoustics	Acoustic receivers for sound in the ocean (e.g. from marine mammals)
Air chemistry	Surface atmospheric CO_2, O_3, BrO, aerosol (BrO and aerosol retrieved in profile 0-2km above ice)
Sediment traps	
Automatic water samplers	Water samples
High-resolution GPS	Position in high spatial and temporal resolution (ice deformation), some with differential GPS, barometric surface pressure or air temperature.
Position	All stand-alone buoy systems are expected to measure geographic position (latitude, longitude) and time

TABLE 3.4: Installations and measurement platforms moving in the distributed network.

Navigation Buoy (NAVB)	Navigational buoys for glider operations
Autonomous Underwater Vehicle (AUV)	Physical and biological oceanography (various parameters, including turbulence), sea ice bottom topography (multi beam sonar), energy fluxes

Autonomous Underwater Vehicles

AUVs and gliders will be launched and recovered from the Central Observatory as required by the measurement plans and as conditions permit. Many details regarding these systems are still to be developed, including: Required conditions at the Central Observatory (particularly if access to open ocean must be maintained), specific drift/transect patterns and mission parameters, specific details of launch and recovery, etc.

Recovery of Distributed Network

Upon completion of the annual cycle in October 2020, consideration must be paid to recovery of assets that were deployed as part of the distributed network. Specifically, sediment traps and water samples must be recovered to obtain the samples and ASFS must be recovered to obtain the full-resolution data. Additionally, all assets that will not be intentionally left to drift beyond the end of the campaign can be retrieved as possible. Retrieval of assets can occur using helicopter flights from the Central Observatory, with the Polarstern after leaving the Central Observatory, and/or with other support vessels that may be present during the final part of the MOSAiC drift.

3.4 Airborne Observations

Airborne observations will be an essential activity within MOSAiC to observe spatial inhomogeneities. They can be grouped into the categories described below. It is anticipated, that all flight coordination and supervision in the vicinity of the MOSAiC site will be done from RV Polarstern.

Ship-based Helicopters (contact: Gerit Birnbaum, AWI (see Table 4.6))

AWI will provide onboard of RV Polarstern two small helicopters for local flights. They have a passenger capacity of max 4 persons (plus one pilot) and can be used for personnel and material transport for example to the sites of the distributed network. Additionally, the helicopters will be used for scientific and navigational observations.

Flight conditions for the Polarstern based helicopters will be determined according to established operation rules, depending in particular on available daylight and acceptable operation temperatures (nominally warmer than -25C). Helicopter missions to fly include:

- ice reconnaissance during steaming, i.e. for camp set up and potential relocation activities
- deployment and maintenance of the distributed network
- visit of other remote sites
- swing load for transport to ice, e.g. supply of a remote ice camp (max. 800 kg)
- Science missions, here in particular:
  - Ice thickness measurements with EM-Bird (main operator: AWI)
  - Cameras
  - ABL measurements with the “Helipod” (main operator: U BS, AWI)
  - Other new payloads (tbd)

Central Observatory-based Unmanned airborne vehicles (UAVs)

UAVs of different size and purpose will be used during the MOSAiC expedition. UAVs range from small, hand-launched devices carrying a camera for visual observation of ice properties, leads etc. to larger devices equipped with various sensors for ABL research, like turbulence probes or BC / aerosol sensors. Even larger UAVs could be used for long range surveys of ice conditions and properties. Depending on their size, different operational regulations will be established. Primary launch and landing of UAVs is expected to occur on a dedicated “runway” on the ice floe adjacent to Polarstern, supported by a small hut/tent. Larger UAVs will need to also comply with the international regulations being established for use of UAVs in the Arctic by the Arctic Council (see www.amap.no/documents/download/2501), or developed by AMAP (see the handbook for scientific data collection by UAVs (http://www.amap.no/documents/download/2283). Local operation of UAVs will be under the control of the RV Polarstern regulations and will need to follow e.g. regulated communication and transmission frequencies.

UAV regulations:

- To fly UAVs, it must be demonstrated to AWI ship leadership that the appropriate permissions are in place and the appropriate regulations will be followed.
- Primary launch and recovering of UAVs shall be from the ice adjacent to the Polarstern.
- Small UAVs may be given permission to launch/land on Polarstern only via consultation and permission from Polarstern captain.

Central Observatory-based Tethered balloons

During the MOSAiC ice drift, a small tethered balloon (9 m^3) platform will be installed on the ice about 500-1000 m away from the ship. Both the electronic winch and the inflated tethered balloon (TB) will be stored in a tent, and are kept in an operational mode all the time. The operation of the TB system is done by 2 persons (AWI), and is limited to conditions with surface wind speed < 6 m/s.

The standard TB measurements by AWI will provide vertical profiles of thermodynamic parameters with high resolution in the atmospheric boundary layer up to about 1500m. In addition, the TB platform is available to carry balloon-borne payloads up to 3 kg of other MOSAiC-endorsed projects, e.g. aerosol measurements by filter or spectrometer. The final strategy and time schedule of the different TB measurement set-ups will be decided once the funding situation of the related projects is clear.

While this small TB system will be operated throughout the entire MOSAIC drift, a large tethered balloon will be installed probably during leg 4 by TROPOS. This large TB platform has the capacity to carry a payload up to 10 kg, with a maximum altitude of 1 km and maximum surface wind speed up to 6 m/s. The scheduled observations with the large TB include basic meteorology, radiation, turbulence, and aerosol properties. Potential use of the large TB platform during leg 4 by additional balloon-borne sensors of other MOSAIC-endorsed projects is under discussion.

Ship-based Upper-Air balloons

During the entire MOSAIC ice drift, 4 daily radiosondes will be launched from the ship. The radiosonde data will be transferred to the GTS in near real time to contribute to weather forecast. Additional ground check procedures for the sondes will allow to later process the data by the GCOS Reference Upper-Air Network, to provide highest data quality and height resolved uncertainty values for the retrieved profiles.

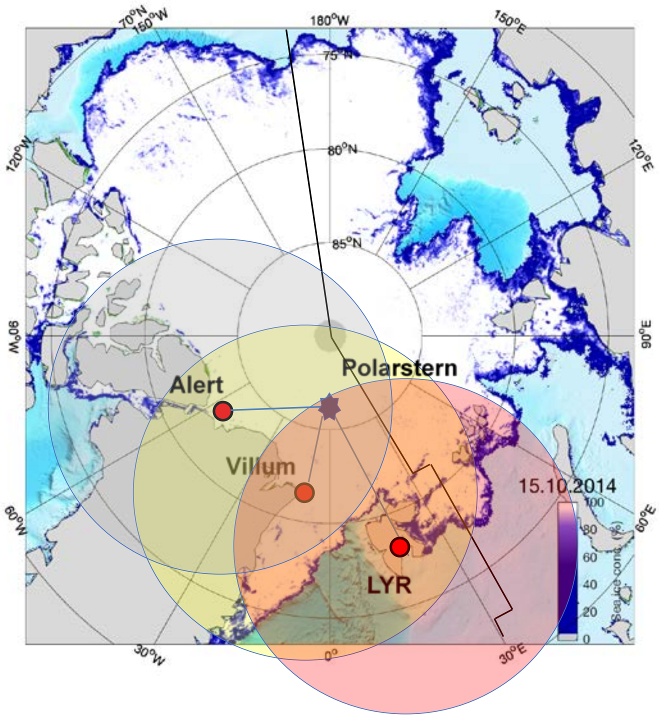


Fig. 3.9: The distance from different Arctic stations (Longyearbyen (LYB), Villum, Allert) to an potential positions of Polarstern during mid of March 2020 (star). The distance from LYB is 600 NM, from Villum 400 NM and from Allert 450 NM. The black line represents the border of the Russian Airspace. (Figure: M. Nicolaus and A. Herber (AWI))

Moreover, ozone sondes will be launched on a weekly basis to obtain vertical ozone profiles up to about 30 km. Furthermore, Cryogenic Frostpoint Hygrometers (CFH) for the detection of stratospheric water vapor, as well as Compact Optical Backscatter Aerosol Detector (COBALD) sondes for the information on aerosol backscatter properties will be launched on a monthly basis.

The upper-air balloon program is coordinated by AWI.

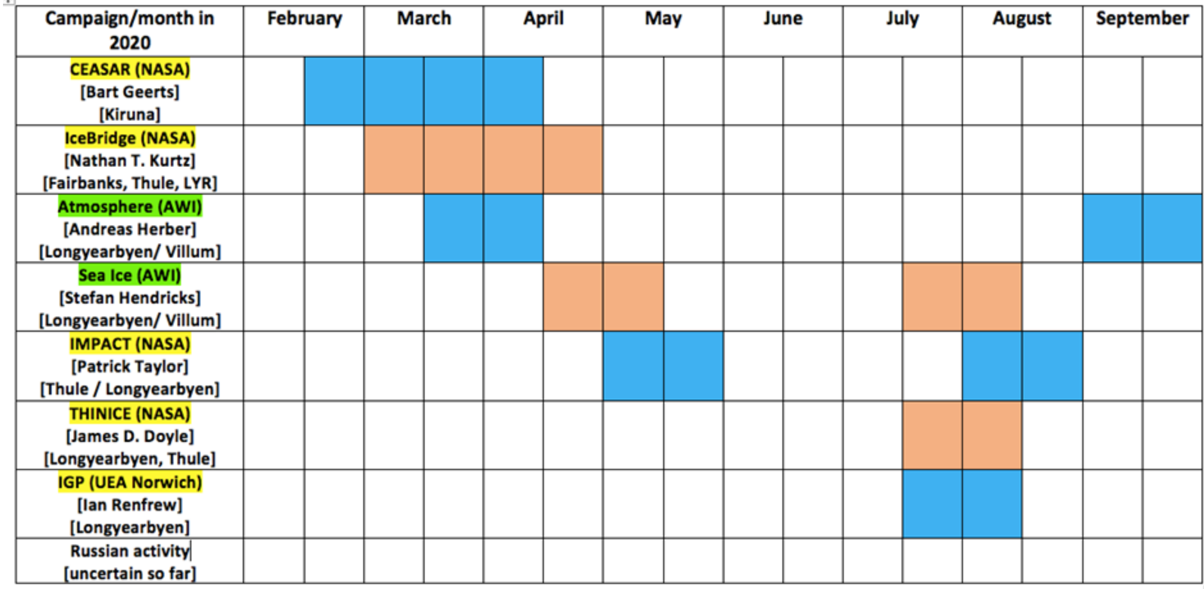
Ship-related airborne activities

It is anticipated, that during several occasions exchange of personnel will be carried out by land based helicopters, and possibly fixed-wing airplanes. The later will require establishing a sufficient runway on a nearby suitable ice floe. This is expected to be built during early spring 2020 and to be maintained until early summer 2020. The runway needs to be at least of 1200 m length and at least of 1 m thickness of the sea ice to allow for landing of AWI's Polar 5 and 6 aircrafts. Ice floe and runway conditions will follow regulations of the Canadian operator of the Polar aircraft. The AWI aircraft can operate out of Longyearbyen (Spitsbergen), Villum (Greenland) or Alert (Canada). Typical ranges for such missions with the AWI aircraft are up to 800 NM with refueling at a nearby suitable ice floe or 400 NM without refueling, which is are shown in Figure 3.9.

In addition to transports, AWI's Polar 5, 6 airplanes are expected to carry out scientific missions between Spitsbergen and/or Northeast Greenland, Ellsmere Island and the MOSAiC drift in spring 2020. These will be organized as part of IOPs and might require landings on the MOSAiC runway for refueling. A second campaign also with both AWI's Polar 5 and 6 aircraft is planned in early summer with the operation base of Longyearbyen.

Russian Antonov aircrafts operating from Cape Baranov on Bolshevik Island shall be used for personnel transport as long as RV Polarstern is within their range.

TABLE 3.5: Overview on the planned airborne operation during MOSAIC in 2020 (blue are atmospheric activities, beige are sea ice activities). The AWI activities (green) are funded and the other airborne activities (yellow) are proposals and under review.



Campaign/month in 2020	February		March		April		May		June		July		August		September	
CEASAR (NASA) [Bart Geerts] [Kiruna]		🟦	🟦	🟦	🟦											
IceBridge (NASA) [Nathan T. Kurtz] [Fairbanks, Thule, LYR]			🟧	🟧	🟧	🟧										
Atmosphere (AWI) [Andreas Herber] [Longyearbyen/ Villum]				🟦	🟦										🟦	🟦
Sea Ice (AWI) [Stefan Hendricks] [Longyearbyen/ Villum]						🟧	🟧					🟧	🟧			
IMPACT (NASA) [Patrick Taylor] [Thule / Longyearbyen]							🟦	🟦					🟦	🟦		
THINICE (NASA) [James D. Doyle] [Longyearbyen, Thule]												🟧	🟧			
IGP (UEA Norwich) [Ian Renfrew] [Longyearbyen]												🟦	🟦			
Russian activity [uncertain so far]																

Scientific airborne campaigns, including aircraft overflights

In addition to transports, AWI's Polar 5 and 6 airplanes are expected to carry out scientific missions between Spitsbergen and/or Northeast Greenland, Ellsmere Island and the MOSAiC drift in spring and summer 2020. These will be organized as part of IOPs and might require landings on the MOSAiC runway for refueling (only in spring). The airborne campaign with AWI aircraft are separated in two parts, the sea ice and snow thickness activity with the aim to adding spatial component to local sea ice and snow mass balance studies at MOSAIC observatory. The second part are an atmospheric program, with Arctic boundary layer study, cloud, aerosol, trace gases and radiation study as contribution to the atmospheric observatory. Main operator for these missions will be AWI, with scientific cooperation by (AC)³ partners.

It is anticipated, that multiple aircraft campaigns from other partners will take place during the MOSAiC campaign. These will be coordinate together with the AWI airborne activity, mentioned above. These will overfly the MOSAiC site, but in normal case without landing. All these airborne activities shall be organized within IOPs, see chapter 3.7 and are planned in the period from early spring to late summer, see Table 3.5. Main operators expected are form the US (NASA), UK (FAAM), and Russia (Zuev Tomks). For example, NASA is planning different airborne campaigns during MOSAiC: IceBridge (ice-surface elevation data over ice sheets, glaciers and sea ice to bridge the gap between the ICESat

and ICESat-2 missions), CEASAR (Cold-Air Outbreak Experiment in the Sub-Arctic Region), IMPACT (Arctic Investigation Modeling Processes of Aerosols, Clouds, and Turbulence), and THINICE (Troposphere High latitude INhibitors to multi-scale sea ICE Predictability). UK it is planned the IGP (Iceland – Greenland Seas) project (UEA Norwich) with a strong atmospheric – polar meteorology focus. The Russian activity from the Zuev Institute Tomsk are still under discussion.

3.5 Hovercraft Observations

It is suggested to use the hovercraft ***Sabvabaa*** during MOSAiC. The hovercraft could be stationed next to Polarstern and would serve different scientific missions as well as it would provide logistical support or help with safety operations. The hovercraft may be used in addition to helicopter flights and in addition to snow scooter trips if they are not possible due to weather / ice conditions or are considered to be risky. Hovercraft missions will last between a few hours to some days, while scheduling these missions needs very generous timing, since driving might be very challenging and take much longer than anticipated. However, the hovercraft provides a save living space at any times.

Possible missions of the hovercraft are

- it may be used to reach nodes of the distributed network for set up, maintenance or additional measurements,
- it may be used to perform additional measurements along transects in the vicinity (e.g. 10 to 20 km) around Polarstern,
- it may be used to perform additional measurements and sampling from thin ice that is not save to work on, e.g. during formation or during melting season,
- it may be used for recovery of instrumentation or even persons after possible break ups of the main floe or parts of it.

The hovercraft *Sabvabaa* has operated 6 summer seasons and 1 full year in the Arctic sea ice. The total time in the ice was 18 months and it travelled over 4000 km over sea ice within the Transpolar Drift. It had also successful cooperation with AWI and Polarstern for deployment (2012) and recovery (2014).

About Sabvabaa

The optimum driving season is from mid-April to beginning of October, because driving is based on visibility and ground contrasts. However, during darkness, reflective stakes (every few 100m) may be deployed to mark tracks and allow driving in darkness. Navigation could be supported from Polarstern, as well as the hovercraft would always be displayed on Polarstern's bridge.

The practical endurance is at least 400 km, but for MOSAiC a distances of 10 to 20km were discussed to enable reaching the middle scale of the distributed network.

Payload of the hovercraft depends on snow conditions and seasons. During summer, 1,5 tons are possible, but during winter it is much reduced due to air escaping in the loose snow, also below -20 C, the skirt gets stiffer and driving sluggish.

Sabvabaa offers accommodation for the pilot and one additional person for long trips and 3 berths for short missions. In transit the capacity are 6 persons in addition to the driver.

Sabvabaa during MOSAiC

Yngve Kristoffersen plans join the entire MOSAiC experiment (12 to 13 months) as the pilot of the hovercraft. We prefers to stay / live on the hovercraft at all times throughout the drift. In addition, one more person should be assigned to the hovercraft at all times (changing between legs). Beyond this, scientists / technicians with specific missions would join the hovercraft missions.

The use of the hovercraft has to be governed by a formal cooperative scientific and cost sharing agreement with NERSC. Otherwise the activity will fall into the category of a commercial operation, which is not the interest of the owner.

Estimated operating costs are 2000 EUR/day, including the pilot, but excluding the fuel. For the entire year, 25 to 30 tons of Polar Diesel are required and need to be provided through Polarstern.

Fig. 3.10: The hovercraft Sabvabba during pickup from Polarstern in October 2012. (Photo: M. Nicolaus (AWI))

Hanne Sagen and colleagues are currently preparing a proposal for a Norwegian call (deadline 9 Sep), which suggests using the hovercraft during MOSAiC. Their scientific interest is to maintain an acoustic source some km away from Polarstern every 4 days. The proposal, if funded through NFR, could cover approx. half of the estimated costs. This proposal is seeking endorsement from MOSAiC.

It may be assumed that the wishes for hovercraft operations may be manifold, such that the hovercraft may be operational most of time during the drift. It would need a small coordination group, as for the other main platforms (e.g. helicopters).

Polarstern could take the hovercraft on board, e.g. on top of containers on the bow, for the transit through open water and then deploy the hovercraft next to the vessel.

3.6 Other Main Platforms

Different platforms will be used across different teams, but are mainly coordinated under the umbrella of the team with most users. This section summarizes these platforms and their capabilities:

Under-ice Remotely Operated Vehicle (contact: Marcel Nicolaus, AWI)

For measurements and observations under sea ice, a remotely operated vehicle (ROV) will be operated throughout the drift on the central observatory. The ROV will be launched though different access holes and has an operational range of 200m around the hole. Main working depth is 0 to 50 m, while maximum rating depends on the sensor configuration. The current sensor suite is shown in Figure 11 and more details are described in Katlein et al. 2017 (doi: 10.3389/fmars.2017.00281). In addition to this sensor suite the ROV has been successfully used to drag under ice nets (ROV-NET), a zooplankton imaging system (LOKI), a 3D stereo visual camera, as well as an ADCP sensor. Additional tasks are currently under discussion. The ROV system requires 3 to 4 persons for operation, depending on sensor configuration.

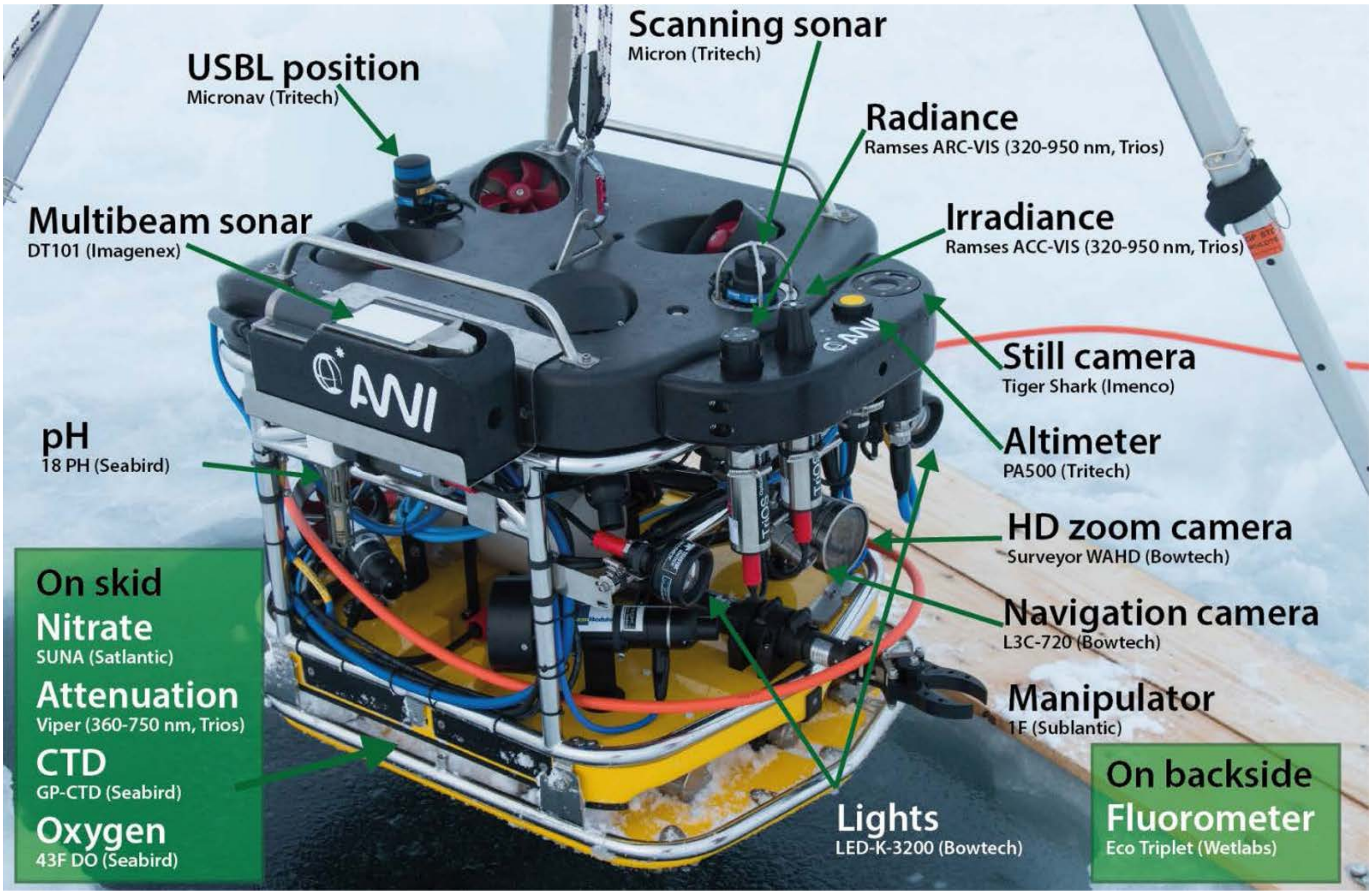


Fig. 3.11: The remotely operating vehicle (ROV) BEAST with its standard sensor configuration. (Photo: M. Nicolaus (AWI))

3.7 Intensive Observation Periods (IOP)

In addition to the standard continuous long-term measurements, there will be intensive observation periods (IOPs) to examine specific processes, times of the year, or opportunistic measurements. IOPs may involve new and/or enhanced measurements within the MOSAiC constellation, associated aircraft campaigns, and/or collaborative measurements from other vessels.

Details of potential IOPs will be developed in the future, but these will fall into two categories: planned and opportunistic. Potential IOP activities, with brief descriptions, might include:

- Arctic Haze (late winter – early spring 2020): This activity would best be built around a coordinated aircraft campaign that is measuring atmospheric composition and chemistry. This could be referenced against the potential atmospheric chemistry measurements made at the Central Observatory and/or from O-buoys.
- Polar Night (late autumn – early spring 2020): Biological activities and ecosystem processes are poorly understood for the Arctic polar night. Intensive biological and ecological observations and process-focused experimentation will be conducted ship-board. From the sea-ice perspective, this period stands out for new ice formation and sea ice thickening, also snow fall and re-distribution will primarily be studied in this period of cold snow.
- Spring bloom (May 2020): The onset of sufficient sunlight into the coupled system presents an opportunity to track the seasonal increase in biological activity. Intensive biological, biogeochemical, and optical sampling can be conducted, potentially using more frequent ROV/AUV missions, ice coring, short-term sediment traps and other approaches.
- Melt season (May – September 2020): The melt season is often triggered by specific synoptic effects and can proceed quickly from a snow-covered surface to one that has growing melt ponds. At this time, it will be

important to have intensified surface energy budget measurements (particularly spatially) and short-term sediment traps. Additionally, upper ocean heat content measurements at this time will be important for characterizing the processes through which solar heat is deposited in the ocean. This season will include extensive melt pond observations and sampling including spatial coverage, optical properties and biological activity.

- Freeze up (August - September 2020): The seasonal end of melt season and onset of freeze unfold via a balance of changes in atmospheric fluxes and a loss of heat from the ocean mixed layer. To characterize this process, intensified surface energy budget and upper ocean heat content measurements are needed. UAS can be used to obtain spatially representative surface turbulent heat fluxes over open water and newly formed thin ice that cannot be made with more traditional approaches.

Tools for the IOPs

- Aircraft campaigns (April – October 2020): A variety of aircraft missions are planned and under discussion, focused on sea ice, surface and/or atmospheric properties with the aim to better understand the interaction between sea ice and the atmosphere. These will take place most likely during the spring into autumn of 2020 with the MOSAiC constellation moving into a domain that is accessible via aircraft missions out on Svalbard. The scientific objectives are, for example, to characterize sea ice and snow thickness and surface properties as well as atmospheric conditions in the Arctic Boundary Layer, and the temporal and spatial variability of aerosols and clouds in the central Arctic. Depending on the specific aircraft mission objectives, enhanced measurements could be conducted on site. For example, in support of an aircraft campaign examining spatial distributions of surface properties such as melt ponds, enhanced measurements of surface properties around the Central Observatory or ice camp, and specific atmospheric measurements related to the temporal aerosol and cloud variability at the central MOSAIC site could be conducted.
- Intensive data assimilation studies (TBD): The radiosonde data set from MOSAiC offers a unique opportunity to evaluate model data assimilation systems and the impact of assimilated data on model forecast quality. Further enhanced studies will be possible with additional radiosonde stations within the Arctic Ocean domain. This may be possible when other ships are available. Potential coordinated activities may include: Japanese Mirai in the marginal ice zone of the Chukchi Sea in October to November 2019, Swedish icebreaker ODEN in summer 2020, and others.

3.8 Events

A major part of the seasonal evolution of the Arctic climate and eco system is not driven by continuous changes, but by rather episodic and discrete events, which trigger significant changes and have major consequences. The observational program will try to describe such events and follow their consequences throughout the year. For this, the weekly schedules (Section 2.6) contain ‘flex time’ and various projects have specific foci on such processes.

While details of the event definitions and consequences for the individual teams and work programs are still under discussion, major events will be defined with respect to

- Storms: Storms have major impacts on the atmospheric conditions, but at the same time impact the snow cover and the sea ice conditions. Finally, the impact on the ice also couples directly into the ocean.
- Snow fall and precipitation: This will change the surface conditions of the ice covered ocean and directly impact the energy and mass balance. But also physical and biogeochemical properties of the surface and the snow pack will be impacted and require additional observations and sampling.
- Leads: Leads represent a significant source of upward flux of heat, moisture, gases, and particles between from the ocean to the atmosphere, and an increase flux of solar energy into the upper ocean. Additionally, leads promote lateral ice melt. Intensified measurements around an open lead would target atmospheric and ocean

heat/moisture fluxes, cloud formation, atmospheric boundary layer modification, surface gas exchange, ocean surface layer properties, ice formation processes, lateral ice melt, and other processes.

- Ridges: Ridging is a significant mechanism through which sea ice increases in thickness and roughness. Ridges that form would provide an opportunity to make additional ice thermodynamic, mass balance, and roughness measurements.
- Flooding and melt pond formation: This will strongly impact the energy fluxes, the mass balance and the particle exchange through all media: atmosphere, snow, ice, ocean.
- Warm water: Upward heat flux from the ocean into the ice and towards the atmosphere. We will most likely encounter warm water events during the drift
- Blooms: Spring and summer bloom events will change the ecosystem in all aspects, but also link directly to bio-geochemical processes and even into physical atmosphere-ice-ocean processes.
- Milestones in the seasonal cycle will be tracked and characterized, e.g. melt onset, the spring and summer blooms, melt pond formation, and the autumn freeze up.
- Beyond those “natural” events, also links to intensified observations will impact the observational program, e.g. to perform additional measurements for ground trothing of airborne and satellite measurements. Then, observations will be directly linked to overpasses.

4. PRACTICAL / LOGISTICAL ASPECTS

4.1 Detailed Time Line (2016-2022)

The current status of the schedule for MOSAiC is summarized in Figure 4.2. This schedule corresponds to the optimal schedule and drift (i.e., plan A). It is planned to start the drift in September 2019 and end in September 2020. The experiment will be split into 6 legs approximately 2 months long (Leg 2 – 5), 3 month during Leg 1 and 1.5 month during Leg 6. The first Leg is longer because it includes the transit to the drift floe. The transit will be joint by the AARI vessel Tryoshnikov to help finding the best suitable floe, to transport the fuel for refueling Polarstern and additional staff that will enable the deployment of the Central Observatory ice camp (see Figure 4.1). After completing the deployments, Polarstern will be stationary anchored to an ice floe. Re-locations of Polarstern may be necessary due to dynamics in the ice pack, but are not planned. Alternative and rescue plans are discussed in Section 4.6.

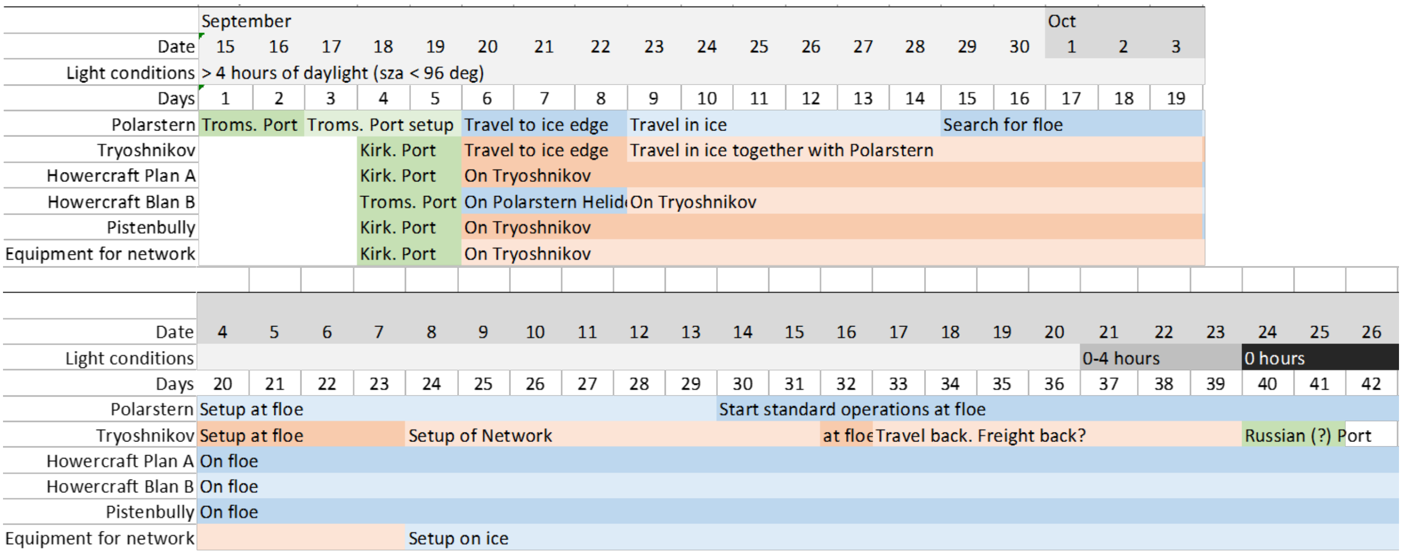
Preparation phase (2016-2019)

There are a number of different events and milestones prior to the start of the MOSAiC field experiment. Table 4.1 summarizes some key dates from today's perspective.

Drift schedule (Sep 2019 – Sep 2020)

The core element of the presented schedules is a full year of observation in the Central Arctic sea ice. This is envisaged from 14 October 2019 to end of September 2020, requiring Polarstern to leave Tromsø in mid-September to have enough time for finding a suitable floe (two weeks) and to set up the ice camp on the flow and the distributed network (Figure 4.1). The setup of the distributed network needs to be finished until daylight is available, at least for a couple of hours every day. Polar night starts on October 24th.

Figure 4.2 shows the split of the experiment into six legs and the timings of refueling and the exchange of crew and scientists with international partner icebreakers from Russia, Sweden and China. After Leg 3, Antonov aircrafts from AARI will be used for the exchange and no refueling will take place.



	September																Oct		
Date	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3
Light conditions	> 4 hours of daylight (sza < 96 deg)																		
Days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Polarstern	Troms. Port		Troms. Port setup			Travel to ice edge			Travel in ice						Search for floe				
Tryoshnikov				Kirk. Port		Travel to ice edge			Travel in ice together with Polarstern										
Howercraft Plan A				Kirk. Port		On Tryoshnikov													
Howercraft Blan B				Troms. Port		On Polarstern Helid			On Tryoshnikov										
Pistenbully				Kirk. Port		On Tryoshnikov													
Equipment for network				Kirk. Port		On Tryoshnikov													

Date	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Light conditions																		0-4 hours			0 hours		
Days	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Polarstern	Setup at floe										Start standard operations at floe												
Tryoshnikov	Setup at floe				Setup of Network								at floe	Travel back. Freight back?							Russian (?) Port		
Howercraft Plan A	On floe																						
Howercraft Blan B	On floe																						
Pistenbully	On floe																						
Equipment for network					Setup on ice																		

Fig. 4.1: Schedule of the beginning of the MOSAiC expedition including the escort by the AARI vessel Tryoshnikov. The expedition starts with the preparation of Polarstern in Tromsø, the travel to the ice edge, searching for a suitable ice flow for the drift and the installation of the Central Observatory and the Distributed Network.

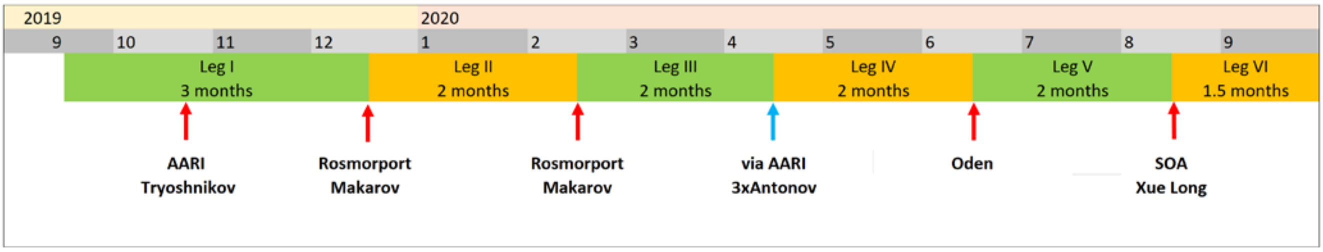


Fig. 4.2: Schedule of the MOSAiC drift starting in mid-September 2019 and finishing end of September 2020. The drift is split in six Legs with regular resupply and exchange of scientists and crew.

TABLE 4.1: Timetable of MOSAiC events before the start of the field experiment.

Timing	**Action**
March 2016	Release of Science Plan (Arctic Science Summit Week)
May 2016	Shipyard Bremerhaven, logistical planning on board Polarstern
July 6th 2016	Meeting with BMBF to discuss EC contribution
July 2016	Implementation Plan V1.0 published on MOSAiC Webpage
Summer 2016	Contracting Russian Nuclear Icebreaker ROSATOMFLOT
September 2016	Science Plan V2.0
Autumn 2016	Memorandum of Understanding about Russian ship for refueling: AARI-Akademik Treshnikov Memorandum of Understanding about Chinese ship for refueling: Xue Long (Snow Dragon) Science Plan community review by IASC members Logistic Meeting in Bremerhaven
Spring 2017	Polar Technology Conference
March 2017	Polar Prediction Workshop, YOPP-Meeting
March 31st – April 7th 2017	MOSAiC Science Meeting during the ASSW in Prague
Autumn 2017	Research Council of Norway open call for proposals for Norwegian participation in MOSAiC
November 13th – 16th 2017	MOSAiC Implementation Workshop at AARI in St. Petersburg, Russia
December 2017	Formalized agreements with funding agencies Formalized contracts with logistic support Formalized collaborations with MOSAiC partners
March 2018	Internationale Polartagung Rostock
May 28th – June 1st 2018	MOSAiC Science Workshop at AWI in Potsdam, Germany
In 2018	Data and coordination workshops, also resulting in a data management plan (see Section 7)
Spring 2019	Observing Team workshops (finalize observing plans, personnel teams) MOSAiC implementation meeting Final participant lists defined
September 2019	Cargo delivery to Tromsø

TABLE 4.2: Timetable of MOSAiC events after the field experiment has finished.

Timing	**Action**
Early Nov. 2020	Demobilization in Bremerhaven; packing, shipping
November 2020	Publish key note publication of MOSAiC
Spring 2021	Workshop for all participants: overview of data status, early results, facilitate coordination, Publish MOSAiC field report (drift description, work on board, key events, meta data, etc.)
October 2021	Start of release of MOSAiC data into public data bases
In 2021	Open Workshop including external collaborators: Modeling and analysis plans MOSAiC Science Conference

Post drift (2020/21 and beyond)

Most scientific analysis, modeling, and integration work will start only after the field phase, but it is an essential element of MOSAiC. Multiple workshops will be held over 2 years after completing the drift in order to coordinate data quality assurance, data archival, synthesis data products, modeling, analysis and publication. However, this will only be the beginning of a long series of collaborations, which will build the legacy of MOSAiC. A summary is given in Table 4.2.

4.2 Drift Trajectory and Re-supply

Trajectory of the drift

To best address the MOSAiC science objectives, the Polarstern will be installed into the newly forming sea ice in October 2019 (before total darkness of polar night) in a region close to some remnant ice floes (to provide camp stability) but in a region with expansive areas of newly forming (or newly formed) first-year sea ice. The observing constellation would then have ample access to a variety of ice types. The potential drift trajectory of Polarstern was simulated by forward-simulations of sea ice drift based on satellite derived daily drift vectors for the years 2007 to 2016. Ideally, the MOSAiC drift will pass near the North Pole but slightly towards the Russian side in approximately April 2020, such that it remains within helicopter range from Cape Baranov (Russia) or Longyearbyen (Svalbard) for its duration. This would be the case for most of the simulated trajectories shown in Figure 4.3. Based on these simulations, the best-suited starting position is around 85°N and 105°E (more detailed in Figure 4.4) in the northern Laptev Sea. The calculated trajectories all fulfill the plan of a transpolar drift towards the North Pole and further into Fram Strait. They almost all extend into the next summer, enabling a drift for at least one full annual cycle. None of the trajectories turns towards the Beaufort Gyre. The actual starting position in 2019 will depend on the ice conditions at the time and updated scenarios of potential drifts in previous years with most similar conditions. The decision on the deployment location might also benefit from current plans for a YOPP/MOSAiC Sea-Ice Drift Forecast Experiment (SIDFEx), see Section 6.1.

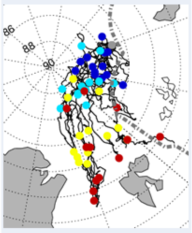
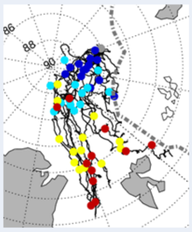
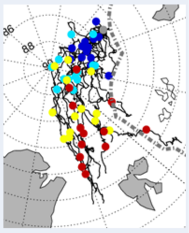
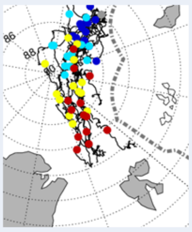
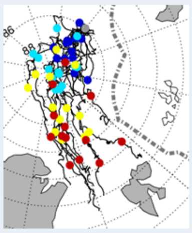
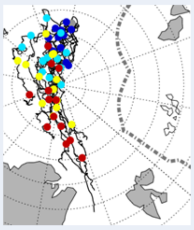
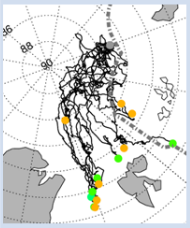
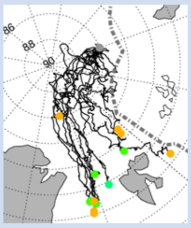
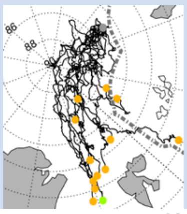
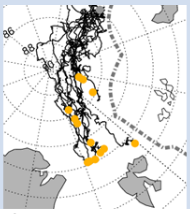
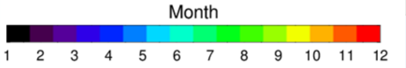
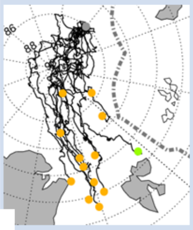
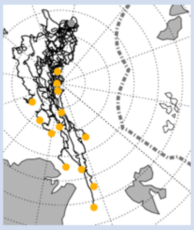
Drift Start	85N°/90°E	86°N/90°E	85°N/105°E	84°N/120°E	86°N/120°E	85°N/150°E
Drift North of 88°N	15 %	30 %	46 %	54 %	85 %	100 %
Drift into Russian EEZ	30 %	15 %	15 %	0 %	0 %	0 %
Survival rate (Ice Con. > 40%)	53 %	61 %	93 %	100 %	93 %	100 %
Avg. drift dist.	2436 ± 265 km	2370 ± 324 km	2556 ± 300 km	2537 ± 300 km	2416 ± 234 km	2295 ± 268 km
Velocity (km d^{-1})	7.30 km d^{-1}	7.11 km d^{-1}	7.04 km d^{-1}	6.97 km d^{-1}	6.67 km d^{-1}	6.31 km d^{-1}
Re-supply ● 15th Dec ● 15th Feb ● 15th May ● 1st Aug						
Drift end				  		

Fig. 4.3: Drift trajectories for selected starting positions calculated for the years (2007 to 2016) assuming a start of the drift on 15 October. The colored dots in the upper row indicate the locations for the potential resupply on the defined dates. The dots in the lower row show the moths when the drift ends. In the upper part of the figure, different criteria for the individual starting positions and the likelihoods are mentioned. (Simulations: T. Krumpen, Figure: M. Nicolaus)

Figure 4.4 shows the simulated drift tracks for a starting point at 85°N and 105°E. The drift tracks are color coded by month to ease the imagination of how a MOSAiC drift could look. However, it has to be pointed out that all these cases only ease planning, but no reliable forecast is possible at this stage of planning. In particular, during summer, uncertainties in sea ice drift detection leads to potentially large uncertainties in simulating a trajectory.

Supply schedule and procedures / logistics

- Mobilization in Tromsø (mid of September 2019):

Polarstern will leave from Tromsø after the completion of the previous TransArc III expedition. Hence all cargo needs to be transported to Tromsø until beginning of September. A detailed schedule of the timings in Tromsø can be learned form Figure 4.1. An extended harbor time, e.g. 5-7 days, is required in order to prepare for MOSAiC in Tromsø. The aim is to prepare as many installations and to empty the ship of non-MOSAiC equipment as much as possible. The following preparations should be done in Tromsø:

- Unpack the scientific equipment into the laboratories and thus reduce the number of containers needed on board
- Install the 5 ARM containers inside and prepare for easy mounting of the antennas after the passage

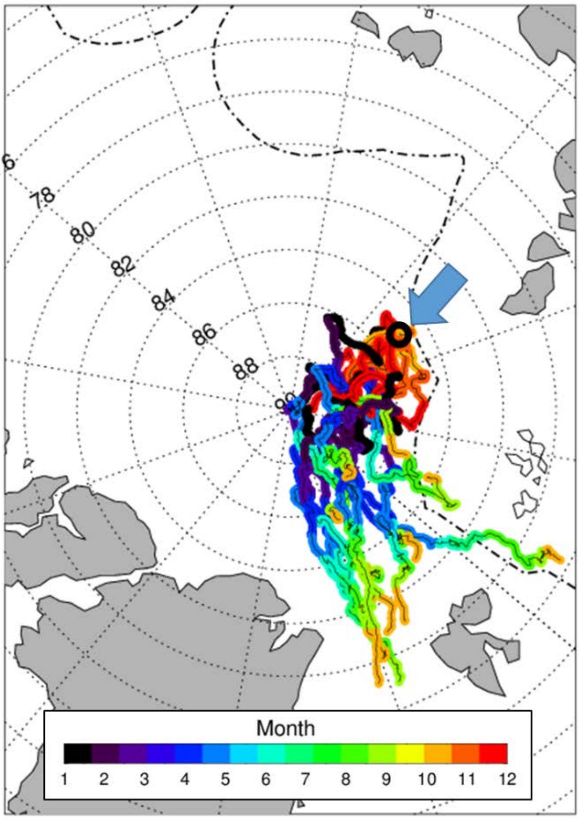


Fig. 4.4: Drift trajectories for the selected starting position at 85°N and 105°E. Colors represent the month of the drift. (Simulations: T. Krumpen, Figure: M. Nicolaus)

- Transit to the Drift Location (20 September – 03 October 2019):

Polarstern will leave **Tromsø** on 20 October 2019 and head to 85°N, 105°E to find a suitable ice flow to start the drift. The estimated transit time is calculated based on the following: TOS (69.665°N, 18.84°E) to ice edge (82°N, 90°E) = 1150 nm @ 9 kn => 5.3 days; Ice edge to starting position (84°N, 120°E) = 130 nm @ 3 kn => 1.8 days. Additional time need to be calculated for finding a suitable ice floe and lead to a total transit of about 14 days and an arrival on October 3rd (see Figure 4.1).

- Installation of Central Observatory and Distributed Network (4-23 October 2019):

The installations on the ice flow next to Polarstern will be established within 10 days. It is planned to start the standard observations mid of October. Additionally, Polarstern will work together with an escort ship (potentially AARI ship Tryoshnikov) to deploy the distributed network. This will be finished by October 23rd 2019. Upon completion of Polarstern activities, the escort ship will transfer fuel (~400 tons) to Polarstern to top off its fuel bunker. Distributed network, and some Central Observatory, deployment crew will be transported back to mainland on the escort ship.

- Refueling 1 (mid December 2019):

In December 2019, we will have a refueling and the exchange of staff and scientific personnel with the Russian icebreaker Makarov provided by Rosmorport. The potential position of Polarstern during the first refueling and the other 4 resupplies are illustrated in Figure 4.5.

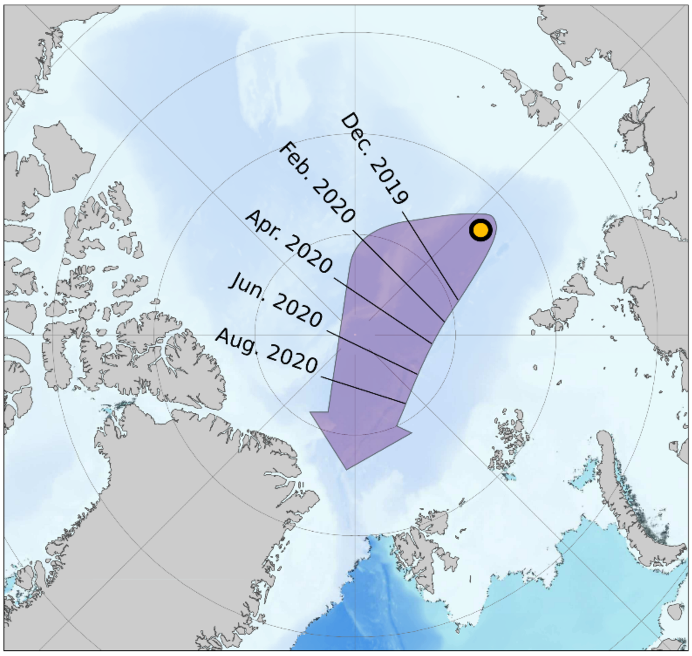


Fig. 4.5: Potential drift corridor based on the simulated drift trajectories shown in Figure 4.4. Yellow dot indicates that starting position of the drift (85° N and 105° E). The black markers indicate the positions of the resupply and exchange of scientists and crew for the currently scheduled dates (please see Figure 4.2). (Simulations and Figure: T. Krumpen)

- Refueling 2 (mid-February 2020):

The second refueling under hardest ice conditions will need again support of the Russian icebreaker Makarov. This icebreaker will refuel 1000 tons of Arctic Diesel. This resupply by the icebreaker will allow a full exchange of crew and scientists, resupply food and other equipment as needed. However, even if the ice conditions hamper Makarov to reach Polarstern and prevent the refueling, the fuel that is stored on Polarstern will serve the daily routines until the next refueling in mid-June.

- Scientific Personnel and crew Exchange (mid-April 2020):

In mid-April 2020, we will have the opportunity to exchange scientific personnel and crew via Antonov aircrafts operated by AARI from Cape Baranov, Russia. The aircrafts will operate in twin flights. To exchange all 90 passengers at Polarstern, three twin flights are necessary. No resupply is planned at this time.

- Refueling 3 (mid-June 2020):

The third refueling in mid-summer is planned to be performed with the aid of the Swedish icebreaker Oden. This icebreaker will be equipped to enable the refueling of 1600 tons of Arctic Diesel and additional fuel for helicopters and aircrafts. This resupply by the icebreaker will allow a full exchange of crew and scientists, resupply food and other equipment as needed.

- Resupply 4 (mid-August 2020):

In mid-August, the last resupply is planned. The Chinese Xue Long (Snow Dragon) vessel will perform the resupply and the exchange of crew and scientists and provide additional 1000 tons of Arctic Diesel. In addition, food and equipment supply is possible.

- End and Return to Port (October 2020):

The observational time series will end on about 18 September 2020. Assets on the ice camp adjacent to Polarstern will be packed. End of the drift will be on approximately 21 September. At that point Polarstern will start its voyage out of the ice and back towards Bremerhaven, with a target arrival date of 30 September 2020. Estimated transit time is calculated based on the following: End drift to ice edge: 100 nm @ 3 kn => 1.4 days; Ice Edge (84°N, 10°E) to BHV (53.54°N, 8.51°N) = 1600 nm @ 9 kn => 7.4 days; Total transit of about 9 days. Consideration will have to be given to the potential collection of distributed network assets.

4.3 Personnel and Personnel Exchange

Persons / berths on board

In total, 96 persons may be onboard Polarstern during MOSAiC, 43 crew members, 47 scientific participants, 4 helicopter personnel (2 pilots and 2 technicians), and 2 Deutscher Wetterdienst personnel (DWD, 1 meteorologist and 1 technician). The 47 scientific participants include the following persons for overarching responsibilities:

- 1 Cruise leader, who is the direct contact for the captain and the crew of Polarstern. The cruise leader will be responsible for all operational aspects as well as the link to land and other ongoing activities related to the MOSAiC field measurements. Other responsibilities will be coordinated with the chief scientist. The cruise leader will be appointed by the executive committee.
- 1 Chief scientist, who will coordinate all scientific work and the daily routines of the scientific and technical work on board. This work will be accomplished in close collaboration with the cruise leader.
- 2 Safety guards (see also Section 4.7)
- 1-2 Data manager (see also Section 7)
- 2 Media/outreach representatives (see also Section 4.9)

The remaining 40 scientists will be organized in the different observation teams, which are described in Sections 2.1 to 2.5. A major part of the berth allocation will be distributed to the teams in order to support the continuous measurements over the annual time series. The preliminary list of berths is as follows:

Atmosphere:	**8 persons**
Sea ice and snow cover:	**8 persons**
Ocean:	**5 persons**
Bio-geochemistry:	**4 persons**
Ecosystem:	**6 persons**

The other 9 persons are not yet assigned. They will be added to the different teams depending on the scientific (or logistic, see below) requirements, which will differ throughout the annual cycle, and between the legs. Priority will be given to those activities that contribute directly to the annual cycle observations, compared to process or event studies. Decisions on allocation of berths will be made by the MOSAiC scientific leadership (Section 4.5).

In addition, there is the common need of all teams for logistical and technical support on the ice to set up and maintain the infrastructure of the ice camp. The need is estimated to be 4 persons, which will mostly support the following activities:

- Setting up the ice camp and maintaining it (tents, hardware installations, holes in ice, floatation and re-location during melt)
- Setting up and maintaining the power lines and other power distribution infrastructure
- Driving Pistenbully or other large equipment
- Preparation of the runway starting in March

- Maintenance of general infrastructure on the ice (scooters, sleds)
- General electrical and mechanical support for science equipment (intensive usage over 12 months)

It is currently under discussion how this need can be accommodated, e.g. to what degree the Polarstern crew can accommodate these needs.

It is planned to increase the total number of scientific personnel during the time of the secondary ice camp (Legs 4 and 5, see Sections 4.1 and 3.5) by approx. 10 persons, which will mostly live in the secondary camp.

Personnel exchange

Scientific personnel and crew will be exchanged after each leg (Section 4.1). In order to provide the best possible continuity in all observations and methods, 8 to 10 persons from the different teams will stay on board for 2 consecutive legs (1 to 2 per team). In addition, the exchange will be organized in a way that overlap for critical team members will be optimized during the exchange either onboard Polarstern or on land. Additional trainings and introduction into the ongoing experiment for each new scientific party before each leg will ease these transitions. It is planned that the exchange includes a common training for about 3 days before departure to Polarstern (Section 4.7).

Mixture of experience, early career scientist involvement

Early career scientists will have a fundamental role in MOSAiC:

- Mixture of experience
- Starting careers based on MOSAiC
- Involvement of early career persons also into organizing the drift and the scientific program
- Contact to APECS established

4.4 Routine operations during the drift

To ensure that field operations are well coordinated and continue to meet scientific and implementation objectives, routine coordination and communication activities are essential. These will take multiple forms and will be generally managed by the on-site cruise leader and co-cruise leader, and an onboard science board that includes a representative from each of the five thematic teams. Routine coordination activities will include both those that are conducted locally onboard Polarstern and remotely. Specific activities are described here.

Daily Forecast Evaluation

(*Attendees: Cruise leader, chief scientist, DWD meteorologist, sea ice team representative*).

In preparation for this meeting the daily forecasts for weather and sea ice must be available. Each day on Polarstern, preferably in the morning, there will be a daily forecast evaluation and discussion. The onboard DWD meteorologist will present the daily weather forecast and the impacts of forecasted conditions on the project will be discussed. Additionally, the sea ice forecast will be evaluated relative to the onsite conditions and weather in order to project the location for the following days. This location forecasting will feed into decision-making and requests for SAR data. The sea ice forecasting and SAR requests could be facilitated from off site, if personnel have sufficient resources.

Daily Science Operations Meeting

(*Attendees: Cruise leader, chief scientist, science board, logistics team lead, data manager*).

A daily science leadership meeting will be held to provide routine guidance for day-to-day scientific activities. This will serve as the daily check-in among the cruise leader, chief scientist, science board and other key science and operations personnel. The agenda will include discussions of the following: daily project plans, team activities, updates on special activities, updates on data management, updates on camp logistics and logistics requirements, instrument problems, personnel issues, overview of safety issues, and requests for support from ship personnel.

Daily Science–Captain Meeting

(*Attendees: Polarstern captain or designee, cruise leader, chief scientist, logistics lead, others as invited*).

The primary objective of this meeting will be to maintain good communication between the science team and the Polarstern captain/leadership. The agenda for this meeting will be adapted to the needs expressed by the captain, but might include: discussion of the weather forecast and implications on operations, an update on standard and/or special scientific operations, and update on any problems, concerns, or safety issues. This meeting will also be the opportunity for the scientific leadership to make requests for ship crew assistance for specific tasks. Lastly, this meeting will be the opportunity to get the captain's clearance for any public relations, media, and/or blog material that will be sent from the ship for public release.

Weekly Program Overview Teleconference

(*Attendees: Project leaders, Disciplinary team leaders, cruise leader (as available), chief scientist (as available), other key personnel will be invited as needed, potentially open to others with general interest*).

The primary objective of this teleconference is to maintain good communication across the science team, both on the ship and off the ship, and to make programmatic decisions. Multiple resources will be needed including: weekly summary provided by the on-site cruise leader and chief scientist, and weekly updates provided by coordinator of distributed network. There will be general discussions of: Operational status (on-site measurements, operational satellite data, operational modeling, data archival, etc.), Major activities (IOPs, coordination with aircraft or other vessels, modifications to deployment, re-supply and crew change schedules, etc.), Outreach activities (blogs and media content), Items requiring international coordination (personnel issues, repair/resupply for instruments, etc.).

Public Relations / Outreach

(*Responsibility: Media/outreach representative*)

The on-site media/outreach representative(s) will be responsible for routine development of public relations materials including blog content, multi-media content and educational resources. They will communicate pertinent content with the cruise leader, who will work with the ship captain to gain approval for official releases of information.

Data Management

(*Responsibility: Data manager*)

The on-site data manager will be responsible for routine operations of the scientific data archive. They will ensure the proper connectivity to observing systems, flow of data, redundant back up, and external transfer of operational data.

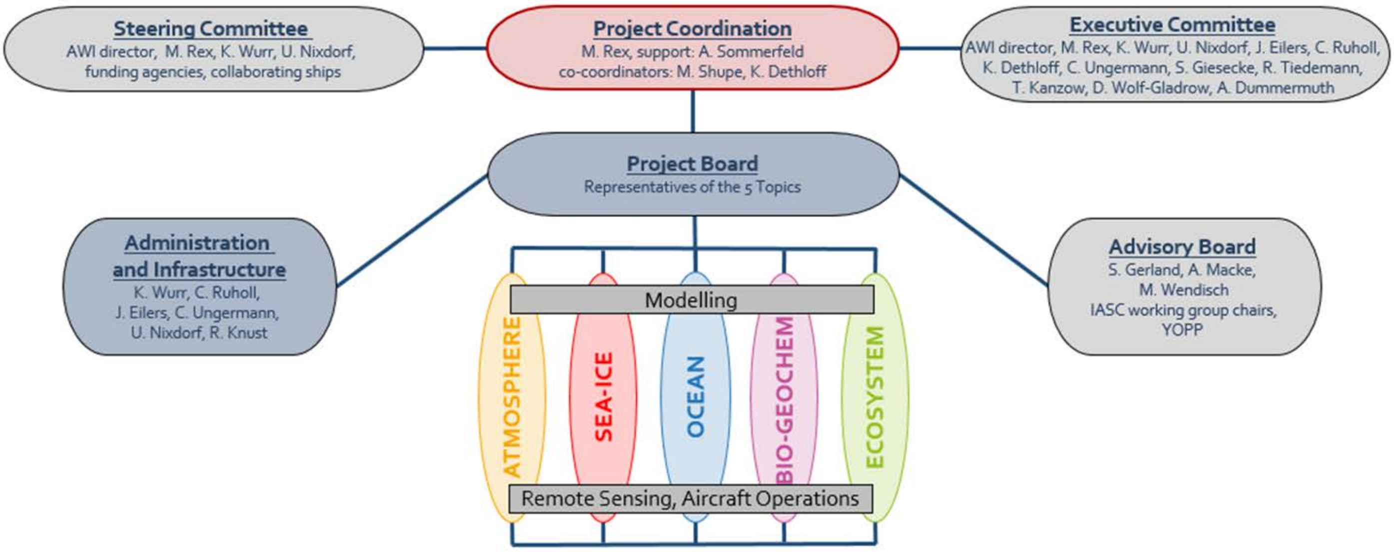


Fig. 4.6: Schematics of the MOSAiC governance structure, coordination within AWI and among all partners, including the teams described in Sections 2.1 to 2.5. (Figure: M. Rex)

They will also work with research teams to ensure proper protocols are followed and to resolve any issues related to data management. This manager will routinely report on status to the cruise leader and chief scientist.

Daily Summary

(*Responsibility: Chief scientist*)

To facilitate proper documentation of the field activities, the on-site chief scientist will be responsible for documenting key daily details from the relevant daily meetings, ongoing activities, operational status, and a summary of evolving conditions (i.e., opening of a lead, etc.). The summary will be completed via a template for consistency over time. These daily summaries will contribute to a weekly report that is provided by the chief scientists to the project leaders for use in the Weekly Program Overview Teleconference.

4.5 Governance Structure

The MOSAiC governance structure is illustrated in Figure 4.6 and includes the scientific leadership for the MOSAiC observational phase that will be provided by an interdisciplinary team of coordinators representing all observing teams and other programmatic priorities. Table 4.3 represents the current status of planning, but will be modified in the course of further planning, also taking significant contributions/funding of international partners into account. One representative for each position will be from AWI, while the other will be from other international institutions. This team of coordinators is responsible for:

- Coordination of international contributions and participation within observing teams. Observing team leads are the points-of-contact for international participants within a given disciplinary area.
- Coordination of activities across observing teams to facilitate coupled system linkages
- Decisions regarding berth allocations
- Oversight of preparatory activities, field operations, and implementation of post-campaign data protocols

TABLE 4.3: Coordinators of the different Teams within MOSAiC with contact dates and Institution. Its embedding in the MOSAiC governance structure is illustrated in Figure 4.6.

Team	**Name**	**E-Mail**	**Institution**
Lead, Co-Lead and Assistance			
	Markus Rex	markus.rex@awi.de	AWI
	Matthew Shupe	matthew.shupe@noaa.gov	U Colorado
	Klaus Dethloff	klaus.dethloff@awi.de	AWI
	Volker Rachold	volker.rachold@iasc.info	IASC, AWI
	Anja Sommerfeld	anja.sommerfeld@awi.de	AWI
Atmosphere			
	Matthew Shupe	matthew.shupe@noaa.gov	U Colorado
	Markus Rex	markus.rex@awi.de	AWI
Sea Ice			
	Donald Perovich	donald.k.perovich@dartmouth.edu	U Dartmouth
	Marcel Nicolaus	marcel.nicolaus@awi.de	AWI
Ocean			
	Christine Provost	Christine.Provost@locean-ipsl.upmc.fr	UPMC
	Benjamin Rabe	benjamin.rabe@awi.de	AWI
Bio-geochemestry			
	Brice Loose	brice@gso.uri.edu	URI
	Ellen Damm	ellen.damm@awi.de	AWI
Ecosystem			
	Rolf Gradinger	rolf.gradinger@uit.no	UiT
	Allison Fong	Allison.fong@awi.de	AWI
Modelling			
	Wieslaw Maslowski	maslowski@nps.edu	NPS
	Annette Rinke	annette.rinke@awi.de	AWI
Remote Sensing			
	Ronald Kwok	ronald.kwok@jpl.nasa.gov	NASA, JPL
	Gunnar Spreen	gunnar.spreen@uni-bremen.de	UHB
Aircraft Operation			
	Manfred Wendisch	m.wendisch@UNI-LEIPZIG.de	ULeipzig
	Andreas Herber	Andreas.Herber@awi.de	AWI
Data			
	Benjamin Pfeil	Benjamin.Pfeil@UIB.no	UiB
	Stephan Frickenhaus	stephan.frickenhaus@awi.de	AWI
Media			
	Ralf Röchert	Ralf.Roechert@awi.de	AWI
Logistics			
	Uwe Nixdorf	uwe.nixdorf@awi.de	AWI
	Marius Hirsekorn	marius.hirsekorn@awi.de	AWI
	Dirk Mengedoht	dirk.menegdoht@awi.de	AWI
	Rainer Knust	Rainer.Knust@awi.de	AWI

TABLE 4.4: Coordinators of the different sub-groups within MOSAiC with contact dates and Institution.

Working group	**Name**	**E-Mail**	**Institute**
Ice floe	Marcel Nicolaus	Marcel.Nicolaus@awi.de	AWI
Buoys	Benjamin Rabe	Benjamin.Rabe@awi.de	AWI
ROV	Marcel Nicolaus	Marcel.Nicolaus@awi.de	AWI
AUV/gliders	Craig Lee	craig@apl.washington.edu	U Washington
UAV	Gijs de Boer	gijs.deboer@colorado.edu	U Colorado
Ice hole	Allison Fong	allison.fong@awi.de	AWI
CTD	Benjamin Rabe	Benjamin.Rabe@awi.de	AWI
Plankton Nets	Allison Fong	Allison.Fong@awi.de	AWI
Tethered balloons	Marion Maturilli	Marion.Maturilli@awi.de	AWI
Mast	Ola Persson	ola.persson@noaa.gov	U Colorado
Helicopter on board	Gerit Birnbaum	Gerit.birnbaum.awi.de	AWI
Sample of ice **Sample of snow** **Sample of water**	Team ECO Team ICE Team OCEAN		

Sub-teams and internal communication

During the preparation phase, we will establish additional working groups, e.g. for coordinating the different topics of Section 3. This will include members from all other teams to allow most efficient planning of measurements, instruments, and infrastructure. All working groups and contact details are listed in Table 4.4.

The project lead and the team coordinators will establish different e-mail lists in order to organize all pre-campaign planning. This will include everybody who is interested in MOSAiC and enable an open information policy. Everyone will be able to sign up for / resign from MOSAiC updates.

4.6 Rescue and Alternative Plans

General risks and potential rescue operations

The analyses of drift trajectories for the last 10 years starting in the Laptev Sea (see Figure 4.4) show that a drift into the Beaufort Gyre is highly unlikely, although it is not possible to exclude this drift path entirely. Should, the trajectory proceed into the Beaufort gyre, the experiment will be interrupted and shifted back towards a region on the transpolar drift pathway. Such a re-location might require the support of a nuclear icebreaker from Russia. Similarly, a major breakup of the camp and distributed network, or a premature drift out to the edge of the ice pack may also require a re-deployment of assets.

In cases of medical emergencies requiring evacuation, long-range helicopter flights will be used from Cape Baranov or Longyearbyen.

Alternative plans

The drift plan and timing described in Section 4.2 is the desired plan and requires a mid-winter fuel resupply, which needs a Russian diesel icebreaker Makarov. If the Russian diesel icebreaker is not able to reach Polarstern due to the ice conditions, the fuel and food stored on board of Polarstern will serve until the next scheduled resupply in mid-June.

If the resupply by Russian icebreakers will not be able at all, two alternative planes are worked out:

- Plan B: Scenario without support from an atomic icebreaker:
  The drift track will be moved to the east (between the Transpolar drift and the route of the former Russian drifting station NP35). Due to thinner ice conditions, this may allow for access by a non-nuclear icebreaker.
- Plan C: Scenario with Polarstern as the only vessel and/or without support for other required refueling:
  like the Norwegian N-ICE cruise in 2015, the Polarstern will leave the ice pack for refueling on its own. This approach will likely require an interruption of measurements at the Central Observatory, but the distributed network will remain in place. Polarstern will attempt to return to approximately the same location relative to the distributed network after re-supply. Refueling might require going all the way to a port, or it could include meeting a tanker ship at the ice edge.

4.7 Safety Aspects during the Drift

Avoiding any kind of incidents and accidents as much as possible is an asset for a successful expedition over such a long time, and in particular due to the remoteness and harsh winter conditions. In order to prevent such incidents, but also to follow national and international regulations, a suite of precautions will be established. The Polarstern captain will have final discretion over all matters of safety both onboard Polarstern and for activities on the ice.

Safety on board

All general safety regulations of Polarstern will be followed, introduced and supervised by the ship's safety officer. These regulations include the nomination of responsible persons among the scientific team (scientists and technical support) for the following safety aspects: weapons (polar bear safety), dangerous goods, radionuclides, samples and frozen goods, lab safety. Most of these people are required to be fluent in German.

Safety on the ice

All participants will go through dedicated "safety on the ice" courses prior to boarding Polarstern. Based on the good experiences of N-ICE in 2015, a course program will be designed and provided during the preparatory days just before each leg. The course will include aspects of:

- use of safety equipment and rules to obey,
- work in Arctic winter/summer conditions,
- proper clothing, introduction into field equipment,

- helicopter instructions (scientific missions on Polarstern),
- general ice camp procedures,
- first aid, and
- polar bear awareness and protection.

Afterwards, on board of Polarstern, ship safety will be trained in a drill. To aid in safety and preparation, AWI and MOSAiC leadership will develop a recommended supply list to help ensure all personnel have adequate clothing, equipment, and supplies for their participation in field activities.

In addition, 2 dedicated safety guards, who are experienced in Arctic fieldwork, will join each leg. These persons will, in the first place, support the cruise leader in any decisions with relevance to safety on the sea ice. They will act as polar bear guards, but also take care of the safety equipment and may take over some duties from safety responsibilities on board (see above).

Dedicated safety briefings will be held for any group leaving the ship further than the established boundaries of the ice camp. All safety equipment will be centrally organized in order to unify it among all participants.

Emergency cases on Polarstern

The rescue capacity of Polarstern is 120 persons, enough to host all involved participants including teams from the additional ice camp in spring, from airborne campaigns, or through helicopter exchanges. However, we will develop an evacuation plan in dependency of the logistical possibilities during the different seasons / phases of the drift. Beyond the evacuation, this plan will also contain more details on rescue installations and equipment on the sea ice. Participants will all be equipped according safety material. All procedures will be taught to all participants prior to the experiment, but also repeated on board after arriving at the vessel.

4.8 Impacts of Polarstern on Measurements and Environment

A major experiment as MOSAiC has immediate impacts on the environment, simply because an icebreaker is operated for 13 months in the Arctic, burning Arctic Diesel and generating heat, noise, and waste water. MOSAiC will develop an Environmental Protection Plan (EPP). This plan will cover the expected impacts of the experiment itself on the atmosphere, the ice, and the ocean, but also on wildlife.

Additional impacts will result from the operations of the supply vessels and different airplanes and helicopters.

Impacts of Polarstern and supply vessels on the environment

- Burning fuel
- Generating heat
- Generating waste water

Impacts of Polarstern and supply vessels on the MOSAiC measurements

- Snow accumulation and drifting
- Enhanced ice melt around infrastructure
- Exhaust leading to contamination of snow and aerosols in the atmosphere
- Impacts on local ocean and atmosphere turbulence
- Light pollution impacting radiation measurements and biology
- Waste release (e.g. nutrients, tracers)
- Sea ice mechanics, local deformation and destruction of the ice floe (preconditioning of cracks)

Precautions will be developed to minimize adverse impacts

- Air sampling will be optimized to avoid local pollution and/or to monitor its occurrence. Additionally the ship exhaust will be directly measured to better understand its signatures.
- additional sampling, measurements
- measurements at secondary ice camp
- waste treatment, scheduled release (if necessary at all)
- Would there be somebody that wants to simulate effects?

4.9 Outreach and Media Concept

Since MOSAiC is an outstanding experiment and the largest of its kind since SHEBA in 1997/98, it will need a well-coordinated concept for media and outreach work. This concept will cover the full documentation of the project, including comprehensive video documentation (including production of video footage for probable TV broadcast), blogs, press releases, in-depth stories, education materials etc. The outreach and media work starts immediately in order to support fund raising and publicity of the project, it covers the drift as the key element, but then also extends beyond the drift. Beyond the scientific elements, MOSAiC will also demonstrate that the Arctic is still a place of good international cooperation and that this project will be a flagship project to bridge gaps between different interests and perspectives with respect to research and stakeholder in the Arctic. As such, MOSAiC will likely also include designated media and outreach projects, which will exploit the vast media and outreach material created during the drift.

A centralized media pool is the core element of the media and outreach strategy. This media pool receives regular updates of material (text, photo, video, audio) from the media contacts on board Polarstern and other project personnel. This material will be accessible for all project partners (through the network of media representatives at the partner institutes). Using such a media pool allows each partner to use common and ready-to-publish material as provided, but also to follow individual ideas and needs, by creating additional products out of the pool and by supporting partner-specific outreach strategies.

The MOSAiC media/outreach team will collaborate with international groups with a strong expertise in media, outreach and education, e.g. polar educators international, APECS. However, it will not be possible to support individual persons or groups (e.g. school classes) through the project. This has to be organized individually by single partners, if needed.

Pre drift

Once the MOSAiC consortium is established, a network of media / outreach contacts among the partners will be established by the media coordinators (Section 4.5). This network will then agree on communication structures and common guidelines on how to promote MOSAiC in the best and most consistent way. This will be necessary to streamline the many individual and national interests that will be connected to the different partners and their role in MOSAiC.

In a first step, hard copies of the MOSAiC science plan as well as fact sheets will support the visibility of the project and sketch the ideas of implementation. These products will also be used for fund raising and display on international boards, conferences, and workshops.

The media network will establish the media pool during the preparation phase. Another task of the media coordinators will be to organize and establish online communication tools: e.g. a web-platform that serves as the main information

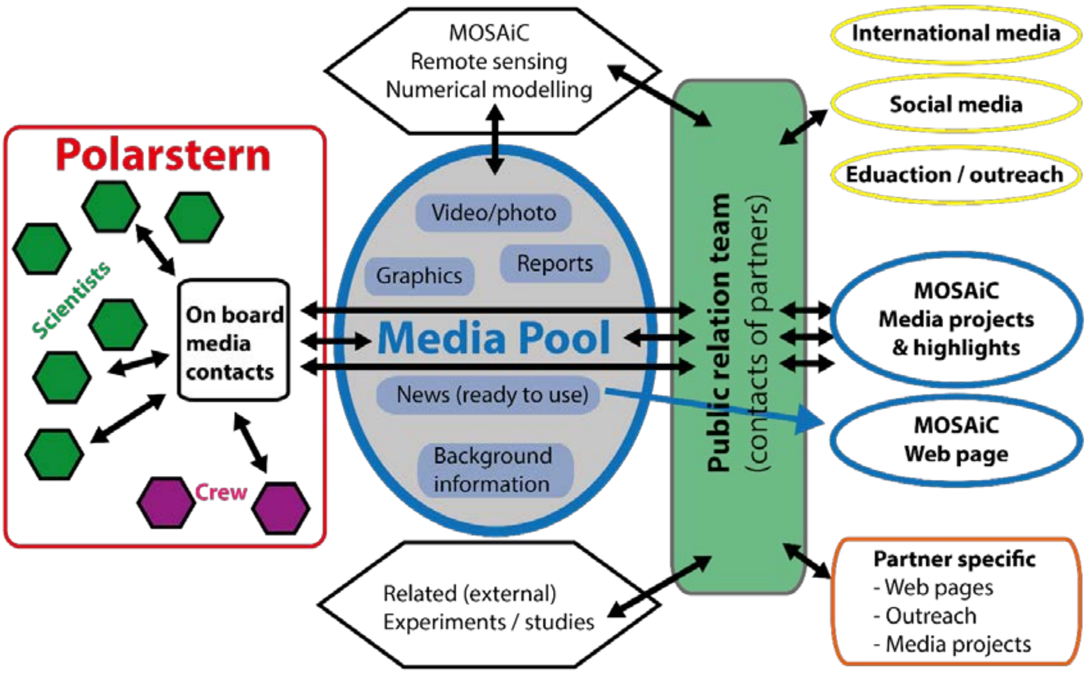


Fig. 4.7: Schematics of the media concept, including the role of the media contacts on board, the media pool, and the actors on the ice and back at home. (Figure: M. Nicolaus)

source of MOSAiC and provides additional material and contact information, an expedition blog and other social media channels.

The media and outreach contacts will ensure that all media contacts on board will receive a briefing prior to each leg in order to have a consistent concept and that all necessary regulations and agreements are obeyed. This will relieve some of the work that is usually performed by the captain and the cruise leader.

During the drift

On board, 2 media contacts will ensure a professional link between the scientists “on the ice”, the home institutes, the general public, and any stakeholders. Their responsibilities are

- Generation of outreach material on board. Depending on their individual qualifications this includes: blogs, social media posts, videos, photography, audio, interviews, educational materials, etc.
- Provision of the material for the media pool, following agreed guidelines on material quality, inclusion of meta data, copyright rules etc.
- Collecting and coordinating pertinent requests from the outside
- Revision and supervision of any material that is going to be published from on board
- Connections to other web sites, portals, and media

All material will be made available in English and usually also in German. But other languages are supported, if possible. Otherwise the home institutes would need to provide individual translations, if wanted.

The 2 media contacts will be sent from different partners during the drift, while the media coordinators will ensure a balance of expertise over the entire drift.

Given the restrictions of telecommunication through the Iridium satellite system for most of the drift, only limited amounts of data may be transferred for media/outreach effort. Major products can only be transferred during personnel exchange (every 2 months). However, telephone interviews and daily reports are possible, but might need coordination (see above).

Post drift

After the completion of the drift, a large amount of media and outreach material will be available from the media pool, but also through contributions of individual scientists. We aim for a comprehensive documentary of the entire drift. However, this will likely require additional funds to reach a professional level of the products.

In this context, it should be considered to apply for dedicated media projects from external funds in the framework of MOSAiC. Such additional funds may enable the generation of comprehensive products, which are beyond the possibilities of individual partners.

4.10 Preparation and Summary Workshops

Performing an observational program that is based on the integration of many methods, partners, interests, and experiences requires an exceptional need for coordination of the various contributors and contributions. In order to achieve consistent and high quality time series observations, it is extremely important to define common procedures and protocols in advance, including instrument inter-comparisons. It is similarly important to coordinate the scientific analyses and interpretation after the field phase.

Team workshops

A series of workshops will be held prior to the field campaign and with enough time to realize the discussed items (mostly in 2018) within each team. The aim is to coordinate and standardize methods and instrumentation, and potentially to introduce the key instrumentation for the drift to all team members. This will help to create teams of comparable experience for the individual legs. In addition, a data management workshop will be held to support consistency with data policies and protocols over the entire experiment (Section 7).

Inter-calibration

Inter-calibration of sensors between the various methods will be an essential part in preparation of MOSAiC. However, most of this work needs coordination within the observation teams and realization on other field experiments and laboratory studies prior to MOSAiC. One essential aspect is the inter-calibration of sensors on autonomous or remotely controlled platforms (e.g. in the distributed network) and those that are constantly maintained in the Central Observatory. The issue of inter-calibration will be a key topic for the team and general workshops.

Integrated workshops

Coordination of the work and personnel on board must cross-cut through all teams in order to obtain truly integrated, coupled-system data sets. To realize this, two preparation workshops will be held (2018 and 2019) with members of all observation teams, remote sensing, numerical modeling, and representatives from coordinated experiments (Section 8.2). These workshops will also involve data management, logistics, and other contributing groups. The aim of these workshops is to develop and refine detailed technical implementation plans for the observational program with a focus on integrating across themes (incl. IOPs, the secondary ice camp).

Post-drift: common analyses and dissemination

Although successfully accomplishing the field measurements during the drift is a primary milestone for MOSAiC, most scientific work will only happen after the field phase. To most effectively use the many data sets, observations, and experiences towards maximum scientific and societal benefit, it is necessary to coordinate data quality assessment, analysis, synthesis, and finally publications. Multiple post-campaign workshops will be held to ensure and support the MOSAiC data legacy (Section 7), and to facilitate broad community use of MOSAiC observations for research, analysis, and modeling. While many of the key details and content of these workshops will require discussion among participants in the observational campaign, these workshops will be open to a broader community of MOSAiC users.

5. IMPLEMENTATION OF REMOTE SENSING

This chapter discusses work in relation to remote sensing from satellites (ground-based and airborne remote sensing can be found in the respective chapters). The inter-agency WMO Polar Space Task Group (PSTG, http://www.wmo.int/pages/prog/sat/pstg_en.php) is strongly supportive of MOSAiC and extensive satellite coverage is expected.

Satellite remote sensing data will contribute to MOSAiC under two different aspects, which have to be handled separately:

1. Remote sensing for scientific analysis
   - ground truthing of existing satellite data with in-situ observations (Section 5.3)
   - collect in-situ data to develop new or improve remote sensing methods (Section 5.3)
   - collect 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 (Section 5.2)

2. Support of MOSAiC operations during pre-drift and drift phases (Section 5.1 and 5.2)
   - sea ice concentration
   - SAR imagery
   - weather data
   - high resolution visual images
   - Ice drift (AMSR2/SSMIS/ASCAT and SAR)

5.1 Pre-drift Coordination of the Remote Sensing Program

Coordinated program for ordering/recording/archiving remote sensing data and determination of latency requirements for decision making. Development of the ground-based remote sensing evaluation program.

- set up satellite remote sensing team
- coordination of satellite acquisitions
  - data availability, incl. ordering
  - potential license issues, research permits
  - data reception and storage
  - data flow, eventually to Polarstern
- define remote sensing needs for field measurements (see Section 5.3)
- develop and coordinate the in-situ remote sensing validation program (Section 5.3)
- develop data concept and contribute to data management plan (Section 7)

Table 5.1 gives an overview of satellite products planned to be used for MOSAiC. For each satellite and sensor a responsible person will be defined to order (if needed) and distribute the data to a central server.

As far as possible all satellite data will be available to all MOSAiC participants. For some satellite products space agencies do not allow free distribution of the data. In that case the group of interested people will be identified and the data released specifically to them.

5.2 Acquisition of Satellite Data during the Drift Phase

Overview of satellites to be recorded

During MOSAiC an extensive satellite data set will be collected. Table 5.1 gives an overview of the satellite sensors that will be useful to support MOSAiC science of all teams. The retrieval of most sea ice related parameters will be achieved. Due to the expected high ice concentration during the drift, observations of the ocean will be limited to leads. Here the sea surface height (SSH) can be observed from altimeters and some of the high resolution optical data might also be exploited for ocean color. Large-scale atmospheric measurements of gases and temperatures will be collected. Most cloud/aerosol measurements, however, will be restricted to lower latitudes. All datasets in blue/grey will be available throughout the experiment, mostly on a daily basis (for visual observations only when sunlight permits). Acquisitions of datasets in green and red need planning and order placement, and may be available only for specific times and locations. Satellites in sun-synchronous orbit with nadir-only observations (grey) will only provide coverage up to 81.5°N and therefore likely have no coincident coverage with the MOSAiC Polarstern drift. The parts of the distributed network, however, which are left behind and continue the drift after Polarstern has left likely will have overlap with these observations.

It is the goal whenever possible to store all listed datasets centrally at AWI and make them available to the whole MOSAiC consortium. For the datasets marked green and red in Table 5.1 some restrictions might apply and additional data proposals or data agreements with the respective space agency might be needed before data can be made available.

All information based on current knowledge and plans, but it has to be considered, that failures of single satellites may happen before or during the drift. For most sea ice parameters, however, there are more than one sensor with similar characteristics available (see Table 5.1).

Transfer and on-board visualization of remote sensing information

To aid navigation and to support scientific planning during MOSAIC drift, remote sensing information shall be used together with model predictions and in-situ information obtained from buoys and ship sensors onboard Polarstern.

Figure 5.1 shows the concept of a support system that is currently under development: The system consists of a data transfer, storage and visualization unit.

Data transfer to the ship is organized by a software with an API for pulling data that connects to different data providers via FTP connection and Iridium. The software is designed such that new data providers can be easily added and update rates for individual data products modified. The ship will be supported with high resolution (SAR) information about sea ice drift, sea ice type and age, deformation and leads. In addition, forecast data is provided by different institutions such as the German Weather Service (DWD). A charting software package on board will allow visualization of incoming remote sensing and model data together with data obtained from on-board sensors such as the ice radar mounted on top of the bridge, or from surrounding buoys. The data are stored on a GeoServer and an archive accessible to all scientists on board.

Satellite remote sensing tasks on the ship and support from home-based teams

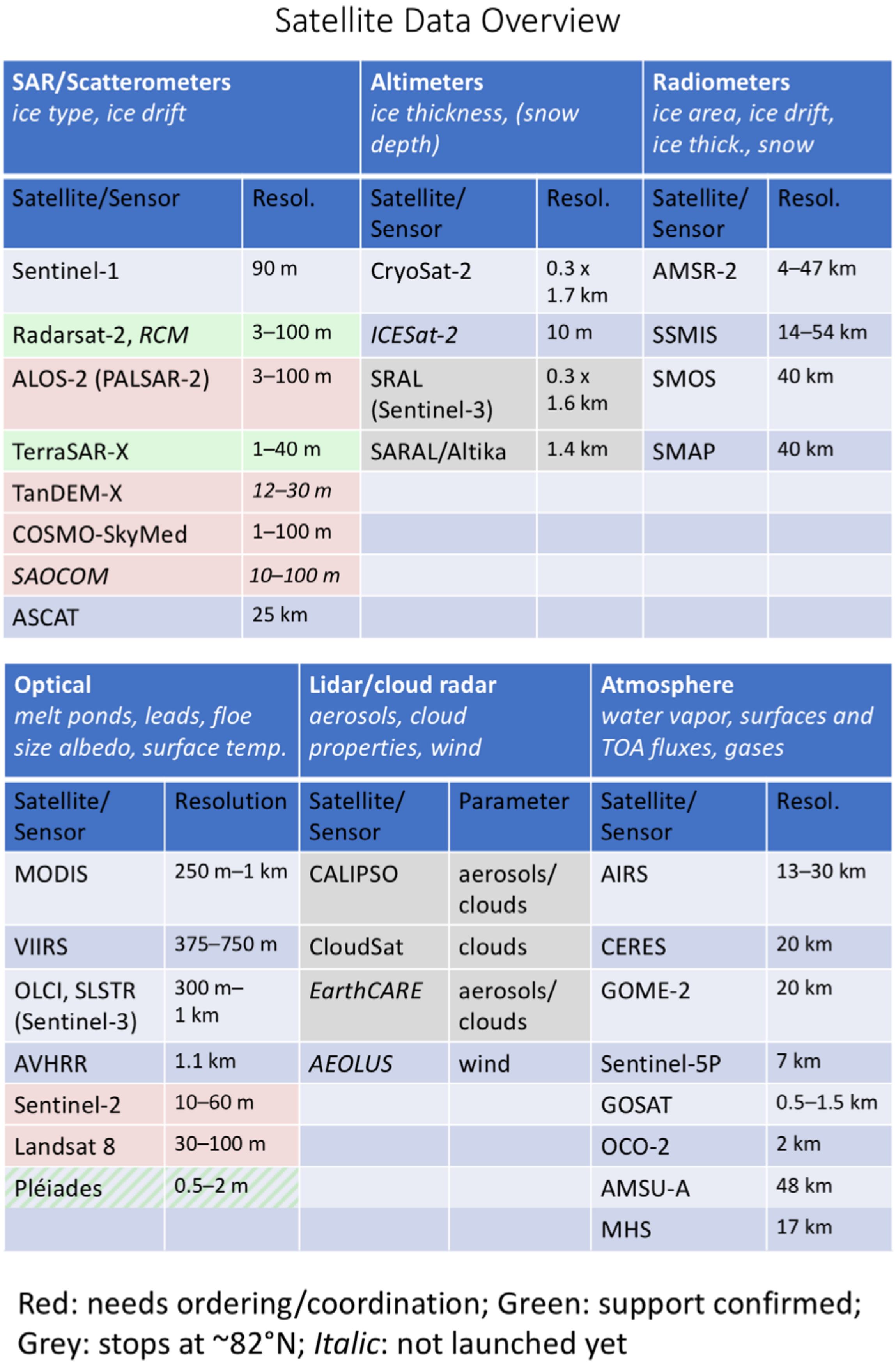
Satellite data acquisitions will be coordination and ordered by home-based teams. Their work involves

(a) checks of fixed acquisitions schemes such as for Sentinel-1 considering the timing of acquisitions from other radar/optical/thermal satellite sensors;

(b) individual orders of satellite scenes in conjunction with special studies (e.g. SAR polarimetry, application of INSAR for retrieval of topography, high resolution optical satellite data), which depends on the availability of suitable data; satellite data acquisitions have to be coordinated with ship-based work on the ice, focusing on ground measurements of parameters required for the interpretation of satellite images (see below).

For every satellite sensor that needs individual ordering (see Table 5.1) one responsible person or institute is defined. That person will coordinate all acquisition requests from the different teams and researchers and order the data. This is needed to avoid conflicts of simultaneous orders from different institutes/researchers.

TABLE 5.1: Satellites and Sensors that can be used for the MOSAiC project.



Satellite Data Overview

SAR/Scatterometers *ice type, ice drift*		**Altimeters** *ice thickness, (snow depth)*		**Radiometers** *ice area, ice drift, ice thick., snow*	
Satellite/Sensor	Resol.	Satellite/Sensor	Resol.	Satellite/Sensor	Resol.
Sentinel-1	90 m	CryoSat-2	0.3 x 1.7 km	AMSR-2	4–47 km
Radarsat-2, *RCM*	3–100 m	*ICESat-2*	10 m	SSMIS	14–54 km
ALOS-2 (PALSAR-2)	3–100 m	SRAL (Sentinel-3)	0.3 x 1.6 km	SMOS	40 km
TerraSAR-X	1–40 m	SARAL/Altika	1.4 km	SMAP	40 km
TanDEM-X	*12–30 m*				
COSMO-SkyMed	1–100 m				
SAOCOM	*10–100 m*				
ASCAT	25 km				

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	Resolution	Satellite/Sensor	Parameter	Satellite/Sensor	Resol.
MODIS	250 m–1 km	CALIPSO	aerosols/clouds	AIRS	13–30 km
VIIRS	375–750 m	CloudSat	clouds	CERES	20 km
OLCI, SLSTR (Sentinel-3)	300 m–1 km	*EarthCARE*	aerosols/clouds	GOME-2	20 km
AVHRR	1.1 km	*AEOLUS*	wind	Sentinel-5P	7 km
Sentinel-2	10–60 m			GOSAT	0.5–1.5 km
Landsat 8	30–100 m			OCO-2	2 km
Pléiades	0.5–2 m			AMSU-A	48 km
				MHS	17 km

Red: needs ordering/coordination; Green: support confirmed;
Grey: stops at ~82°N; *Italic*: not launched yet

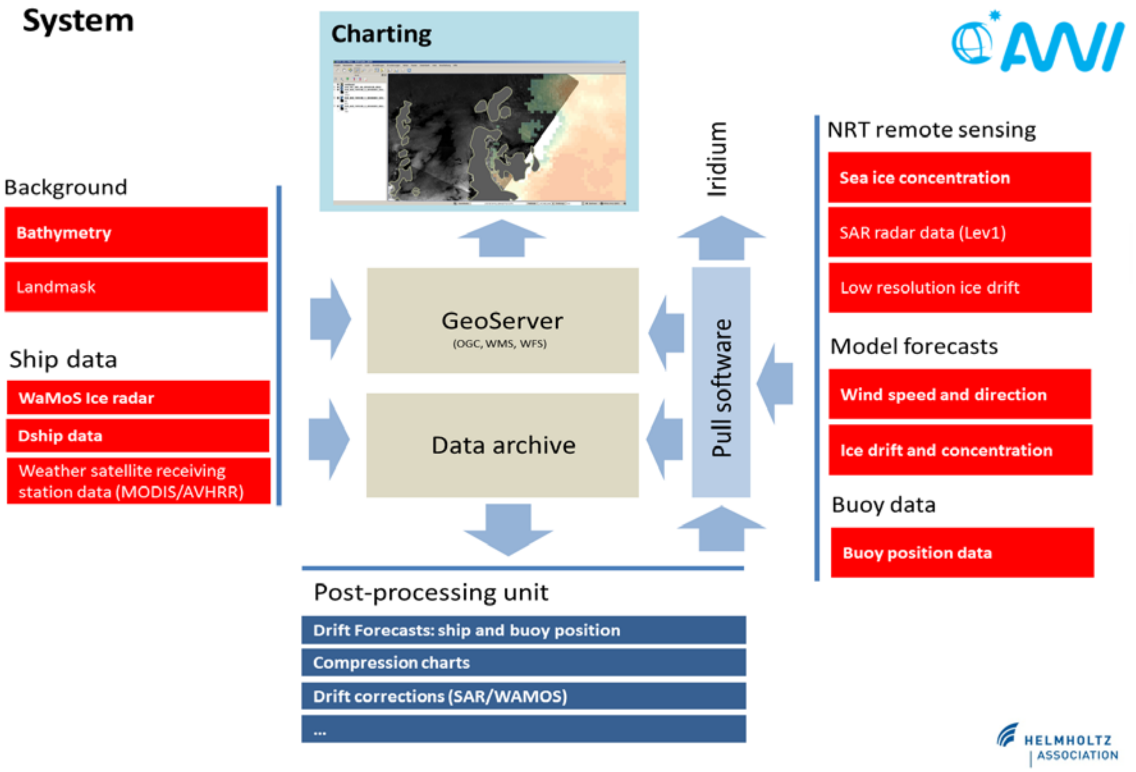


Fig. 5.1: System concept for transfer, storage and visualization of remote sensing and model data in combination with information from ship sensors and surrounding buoys to support decision making during MOSAIC.

Satellite image receiving unit on Polarstern

Most satellite data are received and stored on land, but for some satellite types the on-board satellite data acquisition unit may be used.

5.3 Ground-based satellite remote sensing work

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. 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?

See also the short summary of scientific goals for remote sensing in Section 1.

Remote sensing experiments at the central observatory

On the central floe (and closeby new ice/first-year ice) several measurements for satellite remote sensing validation and the development of new remote sensing methods will be conducted. There will be a reserved undisturbed snow/sea ice area where most of the remote sensing work is consolidated (see map of floe layout in Section 3.2). 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.

Main instrumentation at the remote sensing site include:

a) L-band (1.4 GHz) microwave radiometer with high radiometric sensitivity; multi-frequency P-, L-, C-band radiometer on a mobile sledge

b) Multi-frequency (L/C/X/Ku) polarimetric microwave scatterometers (three systems)

The main objective of a) and b) is to obtain an improved understanding of the microwave radiative transfer and scattering in snow and sea ice, which will lead to improved remote sensing retrievals of, e.g., ice concentration, thickness, and snow properties

c) Ku/Ka-band radar (altimetry), mobile system on a sledge for sea ice thickness and snow penetration/properties studies

d) GNSS Reflectometry antennas for studies about sea Ice thickness, concentration, and snow

e) Infrared and hyperspectral (400–1000 nm) cameras for studies of heat fluxes and optical properties of the snow/ice surface like albedo and melt ponds

All the above measurements 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 radiometer and radar systems mentioned under a) and c), respectively, will be towed along regular transects (weekly) together with ice and snow thickness measurements. Specific snow and ice measurements will also be regularly taken for the evaluation of the ICESat-2 laser altimeter. 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.

Most but not all above instruments are fully funded yet, but for all of them proposals were submitted. A current gap in the ground-based observations are microwave radiometers with frequencies from 10–90 GHz (or better 183 GHz), which are the frequencies currently used for, e.g., sea ice area, type, and snow depth retrievals.

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 ground measurements for satellite acquisitions

Time interval for ground measurements: starting ideally 1-2 days before multi-sensor data acquisitions and ending 1-2 days after. Parameters:

- meteorological data acquired on and around the ship
- photography (also thermal scanning if possible) from helicopter (and from airplanes whenever involved in the measurements), covering as large as possible parts of the satellite scenes
- Data of sea ice topography (laser profiler or laser scanner)
- Measurement grids or “floe-hopping” with helicopter in an area covered by the respective satellite data tp acquire:
    - local temperature conditions, humidity, wind
    - snow height, density, grain size, moisture, presence of special structures (snow crust, superimposed ice)
    - characterization of ice surface (smooth, rough on mm-, cm-scale etc.), ice coring for measuring thickness & salinity, photos 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
- position data from drift buoy arrays deployed in a region around the ship
- during acquisitions of satellite image sequences for deformation studies: aerial photography of evolving deformation structures (leads, ridges, rafting zones)

These special satellite acquisition periods will be, whenever possible, be combined with airborne campaigns when a similar set of detailed information is needed.

6. IMPLEMENTATION OF NUMERICAL MODELS

Important element: forecast during the drift – drift forecast

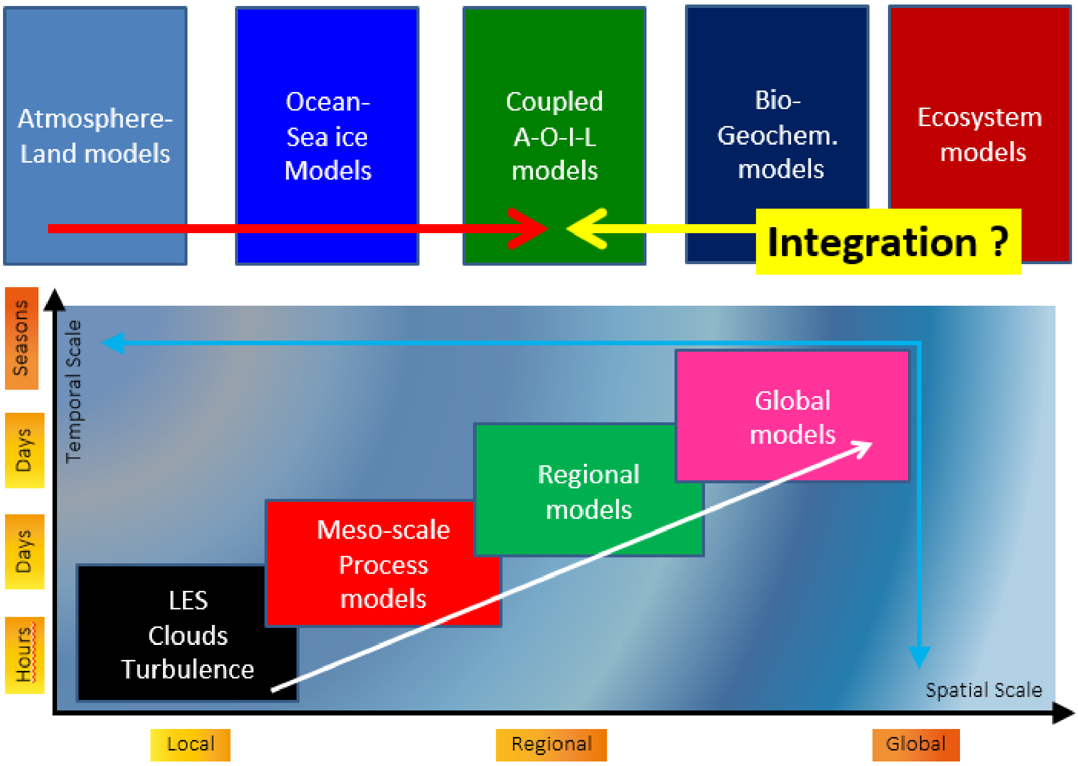


Fig. 6.1: Hierarchy of numerical models in MOSAiC. (Figure: K. Dethloff)

6.1 Operational Forecast of the MOSAiC Drift

Drift forecasts

To support on-site decision making (e.g. sampling, navigation, flight operations, etc.) RV Polarstern will be provided with various forecast products of the ship drift. Forecasts are either made by institutions and send to ship in near real time, or pathways are computed directly on board using a combination of local observations and weather forecasts.

The drift forecasts will be made available to the ship via Iridium and visualized in the on-board charting system for model and remote sensing data (MapViewer [Reference to some other chapter that describes the GIS System?]). In addition to external products, drift forecasts on board make use of local observations. Currently, a number of different approaches are under development and will be evaluated during the RV Polarstern Cruise PS101. Local drift forecasts use a combination of real time ship and buoy positions, satellite and ship radar derived ice drift, weather observations and weather forecasts provided by DWD.

Operations during the MOSAiC drift will benefit from the YOPP/MOSAiC Sea-Ice Drift Forecast Experiment (SIDFEx, http://www.polarprediction.net/yopp-activities/sidfex/). This is an international effort aiming to improve sea ice drift forecasting capabilities, motivated by MOSAiC. Conceptually similar to the “Sea Ice Outlook” initiative, several international groups will submit drift forecasts (from days to a year ahead) at certain times for targeted sea ice buoys in a learning phase during 2017—2019, using any method of their choice but with output in a predefined format. This initiative will then provide guidance both to the MOSAiC starting position (taking into account the various logistical constraints), and to operational decisions during the drift.

Regional forecasts

The AROME-Arctic model, a high-resolution convective-scale regional weather model (Seity et al. 2011), will be used and further developed. The model developments are coordinated internationally within the European ALADIN-HIRLAM consortium. MET Norway has long-standing experience to apply the model system to high-latitude conditions, concerning data assimilation of snow, coupling to sea ice, and high impact weather prediction (Müller et al. 2016). The AROME-Arctic model system has been established as an operational weather prediction model for the entire European Arctic in 2015 and is operated by the Norwegian Meteorological Institute. AROME-Arctic includes an advanced data assimilation scheme (3DVAR) for assimilation of conventional and satellite observations (satellite radiance, scatterometer winds). The data assimilation system is under constant development and new observation types will be included in the near-future into the system (e.g. Atmospheric Motion Vectors, Mode-S winds, Radar reflectivity and winds). Current model developments include implementation of an advanced microphysical scheme (Thompson et al. 2008, Vié et al. 2015), improved sea ice-surface exchange parameterizations, adding a snow layer on top of sea ice, snow and sea ice initialization through data assimilation, sea ice coupling, ocean model (1-dim. mixed-layer model) coupling (Masson et.al 2013).

AROME-Arctic is the only 2.5km non-hydrostatic and operational model system in the Arctic and provides academic users an unique opportunity to study Arctic processes on small spatial scales, takes advantage of the full spatial and temporal information from remote sensing products and provides end-user with a novel capabilities to predict and downscale weather and climate in the Arctic.

For the MOSAiC drift, 2-4 overlapping model domains will be defined in order to follow the observatory. The model system will run with a 3-hourly update cycle and will produce 2-day forecasts twice daily. All forecasts will be freely available in real-time from the thredds server (thredds.met.no).

Quasi-operational 0-10 day regional forecasts will be produced by the NOAA Earth System Research Laboratory for the duration of the MOSAiC drift using a fully coupled Arctic regional model (RASM-ESRL). RASM-ESRL, adapted from the Regional Arctic System Model (Maslowski et al. 2012) was modified for short-term, weather-scale forecasts and includes the following model components: the Weather Research and Forecasting (WRF3.5.1; run with 40 vertical levels) atmospheric model; the Parallel Ocean Program (POP2) model; the Los Alamos Community Ice Model (CICE5.1, Hunke et al. 2013); and the NCAR Community Land Model (CLM4.5). All components, run at 10 km horizontal resolution, are coupled using a regionalized version of the CESM flux coupler (CPL7), which includes modifications (Roberts et al. 2014) important for resolving the sea ice pack response to weather events. Other model optimizations include: a bulk double-moment cloud microphysics scheme for droplets and frozen hydrometeors (Morrison et al. 2009), running ensemble forecasts initialized with the NOAA Global Ensemble Forecast System (GEFS) ensemble members, and extending the model domain to include the Bering Strait and Svalbard. The intention with this model during MOSAiC is to provide forecasts of sea ice properties and to provide a framework for understanding how coupled Arctic system processes impact sea ice prediction on short time scales. The model can also be used as a tool to examine specific processes via sensitivity studies. Initial forecasts for sea ice and other key processes from this model system are available at https://www.esrl.noaa.gov/psd/forecasts/seaice/.

6.2 Data Assimilation Studies

In the global (ECMWF and Japanese Earth simulator by JAMSTEC) and regional (AROME-Arctic) weather forecasting systems the impact of MOSAiC observation on forecast skill will be evaluated. Additional observations of the same types that are already used in the current data assimilation systems (e.g. radiosondes, buoys) will be taken up through the operational stream and compared to experiments without such data for assessing their impact. Advanced observations (e.g. sea ice thickness) require enhanced numerical experimentation. Key to the use of observations in data assimilation systems is their availability through the GTS so that they can be accessed by the operational data pre-processing frameworks.

Additional observations including the increased amount of radiosonde launches (4 per day) at the AWIPEV station Ny-Ålesund (78.9°N, 11.9°E) and, in addition, radiosoundings from the Central Arctic and marginal ice zones from ships, including the Japanese R/V Mirai, Swedish icebreaker Oden, and the Chinese RV Xue Long. A specific focus will be on forecast skill of extreme weather events in the Arctic and mid-latitudes.

Drift forecast products provided from land are based on different models such as the HYCOM sea ice forecast model provided by DMI and operational weather forecast models such as the global ECMWF-IFS (9 km resolution), the global DWD model, the regional synoptic scale (5 km resolution) HIRLAM, and the convective-scale (2.5 km resolution) AROME-Arctic model. The drift forecasts will be made available to the ship via Iridium and visualized in the on-board charting system for model and remote sensing data (MapViewer). In addition to external products, drift forecasts on board make use of local observations. Currently, a number of different approaches are under development and will be evaluated during the RV Polarstern Cruise PS101. Local drift forecasts use a combination of real time ship and buoy positions, satellite and ship radar derived ice drift, weather observations and weather forecasts provided by DWD.

6.3 Process and Regional Modeling of the Sub-systems

Atmosphere

Process modeling:

Process models are the most direct way to link the unique observations at the central MOSAiC observatory and the distributed network to high resolution simulations. A hierarchy of models will be used, namely Radiative Transfer Models (RTMs), Single Column Models (SCMs) and Large-Scale Eddy Simulation (LES) Models. The combined use of these models can contribute to the improvement of sub-grid scale parameterizations of critical processes and feedbacks in the Arctic. The SCM tool is applied to study the behavior of sub-grid-scale parameterizations at the process level, whereas LES can be used as a virtual simulation laboratory to generate three–dimensional information on small–scale turbulent variability and is used to develop and test turbulence and cloud parameterizations for large-scale models.

LES will be performed by a set of different available models (e.g. UCLALES, DALES, WRF-LES, DHARMA, COSMO, and others) in very high spatial and temporal resolutions to describe the boundary layer and cloud structures observed during special time periods or interesting case studies during the MOSAiC drift. The LES will deliver information about the horizontal and vertical heterogeneity of turbulence and advection, convection, vertical fluxes and vertical and horizontal cloud structures in the Arctic boundary layer. The models apply different microphysical parameterizations and the different model configurations give the possibility to investigate the sensitivity of simulations to cloud parameter and processes (e.g., ice particle spectrum, ice nucleation) for Arctic mixed phase clouds. Additional data for the model initialization, synoptic–scale forcing and surface boundary conditions can be derived from operational or reanalysis. In this way transient synoptic–scale weather systems are able to enter the LES domain, but the small–scale boundary layer processes including convective clouds over open ocean areas are resolved by the LES. This will allow statistical comparisons between simulated and measured PDFs of meteorological variables.

The LES simulations will be confronted with cloud and aerosol measurements made during the drift, and with a suite of vertical column observations. On the basis of observed and modelled vertically resolved aerosol and cloud microphysical properties, ground–based radiative fluxes can be extended to compute vertically resolved heating rates to understand surface–atmosphere feedback over the sea ice covered Arctic Ocean. This combination of observations and modelling could provide a promising base for a continuous test bed with respect to improved process understanding and model evaluation in the central Arctic Ocean. The measurements of cloud microphysics, aerosol properties, precipitation and radiation create outstanding opportunities for evaluating the LES under Arctic conditions and for testing and/or constraining the involved parameterizations. With such an approach e.g. the coupling between cloud structures and surface processes and cold air outbreaks could be investigated.

LES inter-comparisons based on the Mixed-Phase Arctic Cloud Experiment (MPACE), the First ISCCP Regional Experiment—Arctic Clouds Experiment (FIRE-ACE) and the Indirect and Semi-Direct Aerosol Campaign (ISDAC) documented a large spread in simulations of mixed-phase clouds in the Arctic. Thus, it is planned to use a set of different models and model configurations. A LES model inter-comparison study will be organized based on cases derived from the MOSAiC measurements and with the international LES community.

Regional modeling:

Regional modeling can help to bridge the spatiotemporal scales from local individual processes to appropriate climate signals. A key issue is here to improve our understanding of climate processes on the regional (ca. 5-50 km) spatial scales where we have still serious gaps in the current understanding of the Arctic climate system and the main drivers for its changes. For example, the observed decline in sea ice extent reflects a combination of various thermodynamic and dynamic feedback processes, involving changes in surface air temperature, radiative fluxes, atmospheric and oceanic heat transports as well as changes in the sea ice drift in response to surface wind, ocean currents, and internal ice stress. Thus, we need an improved understanding of the nonlinear interactions between atmosphere, sea ice, and ocean on the regional-scale. Here regional modeling (of the individual subsystems and the coupled system) is an appropriate tool. These models can be used as test beds to evaluate key parameterizations, and analyze and quantify feedback mechanisms in sensitivity studies.

MOSAiC observations are expected to deliver new and unique data for the process–oriented regional model evaluation. The sufficient resolution to evaluate the regional models can be achieved in combination with simultaneous measurements from moving platforms (ships, aircraft) and satellite observations. Importantly, the planned deployment and operation of the distributed network of autonomous and semi-autonomous sensors around the central MOSAiC observatory will enable the measurement of key parameters on regional model grid-box scales.

Atmospheric regional climate model (RCM) simulations over the Arctic are available from a set of different models. Currently, 11 atmospheric RCMs with varying resolution (of ca. 15-50 km) run multi-decadal long simulations over the Arctic. This international RCM community is organized via the Arctic CORDEX project (http://www.climate-cryosphere.org/activities/targeted/polar-cordex).

Related with MOSAiC, the goal is to organize an atmospheric RCM inter-comparison together with the Arctic CORDEX community with the focus to evaluate specific key atmospheric processes (e.g., low-level mixed-phase clouds, turbulent mixing) in the simulations by using the MOSAiC data. Further, the models will be used to study and evaluate various surface and atmospheric local feedback processes (e.g. surface albedo, water vapor, cloud and lapse–rate feedbacks) which are essential for Arctic amplification. The role of lower tropospheric stability (which controls surface latent and sensible heat fluxes and other atmospheric boundary layer (ABL) processes), and low–level clouds particularly requires more research. There are manifolds, but poorly understood interactions between the surface, clouds, radiative and turbulent vertical fluxes in the ABL in the Arctic.

An advanced understanding of these processes can be achieved by the combined analysis of observations and RCM studies within MOSAiC and related international projects.

Sea ice and ocean

There are many important mesoscale ocean and sea ice processes which can affect the realism of coupled Arctic climate simulations as well as contribute to uncertainty of Arctic climate prediction and predictability. Some of those specific processes and features include: mesoscale ocean eddies, coastal and boundary currents, inertial oscillation, surface mixed layer depth, surface and internal waves, vertical mixing, upper ocean stratification and heat/freshwater content, snow and ice thickness distribution, sea ice melt ponds, porosity, roughness, ridging and other deformation, overall mechanics (i.e. isotropic versus anisotropic rheology) as well as ice/ocean mass and property exchange between shelves and basin, transport and redistribution within the Arctic and through the major gateways, vertical transfer of horizontal momentum and radiative and turbulent energy exchange across the ocean-ice-atmosphere interface.

In the case of the ocean, realistic representation of mesoscale eddies, buoyancy driven coastal and boundary currents as well as details of bottom bathymetry and land geometry have been shown to yield more realistic simulation of the ocean circulation, mean and eddy kinetic energy, mean sea surface temperature, and volume and property fluxes. Similarly, in the case of the sea ice, its deformation together with thermodynamic melt/growth controls the large-scale thickness distribution and its representation requires models with high spatial and temporal resolution.

Coarse resolution global ocean and sea ice models commonly fail to adequately represent such processes realistically, or at all, which leads to a different and less realistic ocean, sea ice and surface climate state, biased compared to observations and high spatio-temporal resolution simulation. Such limitations are hindering our ability to model the past and present and to predict future state of Arctic sea ice. These problems are important, because the on-going reduction of perennial sea ice cover increasingly exposes open water to direct interactions with the atmosphere, including in winter, as thinning sea ice is more prompt to deformation. This in turn influences regional atmospheric conditions, not only along the seasonal marginal ice zone but the Arctic-wide, and appears to impact the troposphere-stratosphere coupling. A more realistic representation of time-dependent conditions of the Arctic sea ice cover and their effect on air-sea interactions is necessary in models and it requires coupling of the respective model components. Moreover, within the Arctic region a vast range of complex and connected feedbacks occur between atmosphere, land, ocean and sea ice that cannot be fully understood, nor downscaled, without including their coupled interactions. The realization of this coupled modeling requirement together with the need for observations of such coupling, i.e. measurements of air-ice-ocean fluxes, have been some of the primary drivers for the MOSAiC experiment., and it is discussed more in section 6.4.

Biogeochemistry

MOSAIC will provide a unique opportunity for process understanding and modelling of the biogeochemical processes at the sea ice interfaces. In particular, the high temporal and spatial resolution of the biogeochemical and ecosystem properties will allow accurate validation of state-of-the-art sea ice and coupled sea ice-ocean biogeochemical models. The annual time-scale of the observations will allow the understanding and modelling of the dynamics of the least sampled seasons, such as winter and autumn. There are still large unknowns in sea ice biogeochemical properties and processes, and this is particularly true for the little known central Arctic. State-of-the-art models focus mostly on primary producers with little functional diversity. Different type of primary producers are for example differently contributing to carbon cycle paths: while single small cells tend to feed into the microbial loop, large and aggregated cells are less effectively degraded or grazed and can represent a significant carbon sink to the bottom of the oceans. Bacteria and zooplankton play potentially a crucial role in element recycling the former, and in regulating primary production as well as mediating energy transfer to the higher trophic levels, the latter. MOSAIC will provide a perfect workbench for investigating the role of different functional groups and their functional diversity in the whole central Arctic marine food web. The complexity of the sea ice and coupled sea ice biogeochemical models is often attributed to the little knowledge and limited observations available for model validation. MOSAIC will provide a unique dataset for both simple model to be able to increase their complexity and to more complex model to test their current performances.

Ecosystem

Ecosystem models in the Arctic and sub-Arctic seas do exist, and primarily focus on the responses of lower trophic level processes, specifically primary productivity, to major physical and chemical drivers. Several models attempt to integrate sea ice biogeochemistry and ecosystem processes into physically coupled models, but the ecosystem components are typically over-simplified. An ice algal ecosystem model has been successfully coupled with global physical and open-ocean pelagic ecosystem models, resulting in better resolution of ice algae community contributions to primary productivity estimates. However, great uncertainty in the further development exist due a) the lack of understanding regarding the biological processes in the Arctic ocean, b) the currently poor data availability from many parts of the Arctic, specifically the pack ice region, and c) uncertainty in many physiological parameters that relate biological rates (e.g. respiration, production, growth, grazing etc) to environmental variables over complete seasonal cycles. For example, winter data for most biological processes of interest either do not exist or are scarce. Similar to numerical modeling of ecosystems, satellite data based estimations of primary productivity are hampered by the lack of physiological data and incomplete information on the seasonal variability of nutrient concentration and distributions, which are relevant and critical to such efforts.

The recent model inter-comparison highlights substantial challenges in implementing realistic ecosystem models focusing on the most basic biological variable primary production. Model outputs revealed substantial differences in primary productivity output and distributions; additionally outputs across different models did not agree even in the fundamental aspect of whether nutrients or light are limiting algal growth, putting into question whether current models are robust enough for predictive capabilities for the future status of Arctic ecosystems.

Ecosystem model improvements require improved cooperation and communication between field ecologists making discrete measurements and ecosystem modelers. Time series data from several locations are required to develop and test approaches to numerical modeling of specific aspects of both the sea ice and pelagic ecosystems and their coupling. MOSAIC will play a highly important role in providing numerous new observations for a wide range of modeling efforts, including 1D to 3D ecosystem modeling, and for areas where biological activity might affect gas exchange, or DMS production.

6.4 Coupled Climate Modeling

Stand-alone atmosphere-land or ocean-ice models do not include fundamental surface feedbacks at the marine interface (e.g. air-sea heat fluxes controlled by sea ice deformations in winter that feedback to surface albedo in spring), which negates strongly non-linear coupling known to be temporally and spatially sensitive and important in polar regions.

Coupled atmosphere-ice-ocean regional climate model (RCM) simulations over the circum-Arctic are available from a set of different models. Currently, 5 coupled RCMs (HIRHAM-HYCOM-CICE, HIRHAM-NAOSIM, RASM, RCAO, REMO-MPI-HAMOCC) with varying resolution (ca. 25-50 km in the atmospheric model and ca. 10-25 km in the ocean model) run multi-decadal long simulations over the Arctic. Other coupled models (COAWST, CRCM-NEMO) are under development. This international Arctic RCM community is organized via the Arctic CORDEX project (http://www.climate-cryosphere.org/activities/targeted/polar-cordex).

Coupled RCM modeling in the Arctic is scientifically driven by questions like: What are the main drivers and feedback mechanisms for rapid sea ice loss? What is the relative role of the different processes (such as albedo, clouds, cyclones, ocean heat transport and mixing) for the sea ice variability and extreme anomalies? What is the impact of mesoscale atmosphere and ocean processes on the coupled system? What are the mechanism for the statistical correlation between sea ice decline and changes in atmospheric circulation patterns?

There are a number of reasons why global climate models (GCMs) may not be able to simulate the rapid environmental change in the Arctic, including: (i) poorly resolved clouds and cloud processes impacting net surface radiation, (ii) boundary layer and bulk surface flux parameterizations, (iii) unresolved oceanic currents, eddies and tides that affect the advection of heat into and around the Arctic Ocean, (iv) crudely represented sea ice mechanics, surface snow processes, sea ice melt ponds, and surface roughness which affect ocean-ice-atmosphere surface momentum and energy transfer, and (v) poorly resolved land surface processes which affect the freshwater flux to the Arctic Ocean and the energy and momentum exchange between the land and atmosphere.

Related with MOSAiC, the goal is to organize, in concert with the atmospheric RCM inter-comparison, a coupled RCM inter-comparison together with the Arctic CORDEX community. Focus will be the study of key ice-ocean processes (e.g. upper ocean temperature and salinity structure, surface mixed layer, eddies, ocean convection), sea ice production and processes (e.g. thickness distribution, deformation, export), atmosphere-sea ice interactions, and atmospheric processes (e.g. clouds, ABL), cyclone activity (incl. polar lows and cyclone-sea ice interactions). The MOSAiC data will help to carry out such an important process-oriented evaluation.

7. DATA POLICY AND MANAGEMENT PLAN

To manifest a major international experiment like MOSAiC requires a very high level of coordination and cooperation on all aspects of the project and in particular on the production, treatment, and usage of data. A clear data policy is essential to support consistency across the MOSAiC endeavor, promote fairness, facilitate collaboration, and ensure a strong MOSAiC legacy that will enable a wealth of scientific advancement. A data policy team, in coordination with MOSAiC scientific leadership, develops a policy that outlines specific expectations and requirements for all MOSAiC data, including data protocols, management, archival, availability, ownership, and acknowledgement.

To gain endorsement for participation in MOSAiC, all participants (including both the producers and users of data) must agree to the conditions of the data policy. The full text of this data policy will be included in future versions of the MOSAiC Implementation Plan when available.

7.1 Outcome of the St. Petersburg Implementation Workshop

The basic principles of the data management plan were fixed at the St. Petersburg implementation workshop in November 2017, having installed the MOSAiC data group, consisting of data speakers per MOSAiC group. Here, openness of data has been agreed upon to be the guiding principle for the interdisciplinary research connected to the project. As central goal a MOSAiC data legacy was identified, i.e., a complete set of MOSAiC research data that is managed homogenously and published in an open access data journal. Furthermore, mile stones were defined, helping to concretize the order and time of necessary steps. As an important tool, MOSAiC Data Workshops are envisioned, that will serve to discuss the state of the MOSAiC data product, identify gaps and define measures for closing these. Furthermore, data principles and data technologies for support of interdisciplinary research will be in focus. From the technical point of view the St. Petersburg workshop established a vision of largely automatized data flows, requiring new data storage (MOSAiC Central Archive MCA) and processing systems on board Polarstern. The operation of this platform requires continuous data science support on board Polarstern over all legs. A land-based MOSAiC data scientist will be taking responsibility to monitor and control data flows from Polarstern to Bremerhaven, and assist delivering data products to the on-board scientific users. He will also develop the tools and virtual environments to access, visualize and analyze data from the Polarstern MOSAiC data archive. Thirdly, he will support the implementation of the MOSAiC Data Management Plan in dialogue and cooperation with the scientific users and data providers.

Further important points were 1. the problem of bandwidth management for the IRIDIUM connection to Bremerhaven and several other institutes, 2. radio interference of multiple sensors operating and transmitting data in parallel, 3. necessity of an instrument list as basic management tool for managing data-flows and for estimating bottlenecks (see 1. and 2.).

Milestones:

30 Oct 2020: drift data log closed; buoy starts logged, stops later

31 Jan 2021: primary sensor and fast analyses sample data available within the MCA

30 July 2021: *predetermined key data* from analysed samples in MCA – Data Workshop

31 Jan 2022: all data from analysed samples in MCA

1 Jan 2023: the MCA release goes public, open for follow-up MOSAiC data/ products

Result data from analyses of all samples will require up to 72 months after drift data log is closed; e.g. Ecological-omics data.

7.2 The MOSAiC Data Group: Development of a Data Management Plan

A data management plan (DMP) will be developed prior to the start of the drift as the result of different participant workshops in 2017 and 2018 (Section 4.1). It will be based on input from the project data manager, PANGAEA editors, the project scientists and specific requirements associated with all partner institutes and other data repositories. MOSAiC will not develop new databases or portals. It will make use of the established workflow and archiving procedures of PANGAEA - Data Publisher for Earth and Environmental Science, operated by AWI and the Center for Marine Environmental Sciences, University of Bremen (MARUM). During the runtime of the project, the system may implement new complementary technical developments from related projects and programs e.g. as the Integrated Arctic Observatory as part of the FRAM infrastructure and YOPP.
The DMP will include an overview of the platforms, its operation in terms of data output and how its metadata associated with mounted devices and sensors will be handled. It will describe additional requirements in terms of data acquisition and transfer as well as necessary hardware extension on board and ashore. Furthermore, specification of data processing steps (levels) is required, and a concept for the storage of data of different levels. Metadata of measurements and sensors include airborne campaigns overflying the ice camp, scientific ship operations, and satellite data recorded during the drift (Section 5). Part of the metadata will be the institute and responsible investigator for the respective instrument/datasets.

The DMP will define the flow of metadata and data from the platforms and sensors to the storage archive. The list of data types includes technical and scientific formats and expected volume, supplemented by an inventory of parameter with unit that will be recorded. The data model of the central archive (Pangaea) mirrors the workflow of meta-/data archiving from start of the campaign until the final publication procedures. The community will be informed about the data system and the workflow by the data management during the workshops and by a manual (wiki), the final public availability of the data will be based on the data publishing guidelines.

With an agreement of all partners, a common data policy will be published as an annex to the DMP. Important part will be the definition of a moratorium period. All data can be password protected after import. After the moratorium data will be accessible in Open Access by the scientific community.

The DMP will include a list of expenses and personal required for the MOSAiC data management.

Structure of the DMP has been defined at the St. Petersburg Workshop. The MOSAiC Data Group will work on it until spring 2018.

7.3 The Technical Concept for Supporting the Data Life Cycle in MOSAiC

The full data life cycle is in focus of the data flow framework O2A (Observation to Archive), developed by the AWI computing center for managing data from research platforms. Its central components are 1) the Sensor-web: a web-service to register sensors with metadata and documentation for its operation. 2) the raw data ingest framework (RDIF): for managing the data flows into mass storage systems over different channels of data transport, 3) the workspace: a set of virtual data processing tools with access to the mass storage systems, 4) semi-automatized data publication: the submission of quality managed data and metadata to PANGAEA, involving curators for final acceptance and archiving. To realize the operation of such a system, the systems currently operated at Bremerhaven require mobilization to Polarstern. Therefore, Polarstern will be equipped with new storage and processing capacities, and a virtualization environment that will also host data management services like Sensor and user-specific applications for data processing.

7.4 The Role of PANGAEA as MOSAiC Data Repository

The data of MOSAiC will primarily be archived, published and distributed through the open access data library PANGAEA - Data Publisher for Earth and Environmental Science (http://www.pangaea.de). PANGAEA is a member of the World Data System (WDS) of the International Council for Science (ICSU), hosted by AWI and Marum. Institutional technical operation includes hardware/software, Internet connection, maintenance, web services, and backup in two regionally separated tape archives.

The system is aimed at data from earth system science. The data model is focused on the storage of results from natural science disciplines, georeferenced in space and time. Operated as a long-term archive, it can also be seen as a library, providing the infrastructure and bibliographic citation for scientific results in Open Access.

After an editorial review and a technical quality control on consistency, validity and completeness, data are stored in a consistent format with their meta-information in a relational database. Datasets which do not fit into the relational system due to specific formats are stored in a tape drive robot system with their metadata, a description and the storage link in Pangaea. The editorial system for new metadata definitions, data import and editing of datasets is established through a client/server system which is the major front end for the work of the data curators. Datasets can be password protected for a moratorium period; metadata are always visible. The author can choose between different Creative Commons Licenses, the metadata have the license CC0 (public domain) and are always open access.

Data will be described using the metadata format ISO 19115. It is distributed on the Internet through web services with various protocols, and others Open Access Initiative – Protocol for Metadata Harvesting (OAI-PMH) and web catalogue service. This enables metadata harvesting by portals, library catalogs and search engines. Thus any dataset in Pangaea is searchable and accessible via e.g. the Pangaea serach engine, Google, DataCite or WorldCat. Part of each dataset is a data-citation including a DOI (Digital Object Identifier) for persistent identification. Central table in Pangaea will be a term catalog as an open dictionary for the definition of scientific parameters. New parameter can be defined at any time on request to the data librarian. The content of Pangaea is mirrored in a data warehouse, allowing the extraction of individually configured subsets of data from the inventory for compilations or further processing, e.g. visualization or modelling. Metadata may be mirrored into other databases and distributed via specific portals depending on the requirements of the project partners.

7.5 Project Data Management and Publication

PANGAEA data curators will operate as members of the project in the Data Group, considering the proximity to the data producers. Under the supervision of the project data manager and the Pangaea data editorial board, they will collect metadata from platforms timely after production or monitor automatized data flows on-board in connection with the MOSAiC data scientist and underway data service support. Data from the investigators will be handled in close cooperation with the data scientist, data curators and editors. Prior to import, data undergo a technical quality check. After archiving, the data publication will be communicated with the author(s) until her/his approval. This workflow is documented and accessible through the Pangaea ticket system.

The storage of near real time (NRT) data from selected platforms/devices/sensors including the use of monitoring dashboards is not yet part of the Pangaea workflows and thus has to be developed in close coordination with the computer center of AWI. A similar process has already started through development of the data infrastructure for the FRAM project. SensorML as an OGC conform format will be adopted for describing devices/sensors and which is widely used in the international community. The NRT data streams can be accessed via web services in various formats.

For publications, e.g. cruise reports, (hand)books, manuals etc. Pangaea also provides archiving services in a library with availability via catalog and DataCite incl. DOI provision in cooperation with the TIB (Technische Informationsbibliothek Hannover).

Validated data from all platforms/devices must be submitted to Pangaea within one year after completing the drift. Exceptions from this, large data sets can be stored in self-describing data formats with description in a dedicated project workspace next to the Pangaea infrastructure for internal data sharing. This is important for all project participants, including the modeling and remote sensing applications, as integrative elements of MOSAiC.

After the drift, dedicated data collection will be published in Open Access through data journals (a.o. Earth System Science Data (ESSD) of Copernicus, Scientific Data of Nature) for proper citation in ongoing publications. Pangaea will act as the supplement archive to ensure persistent identification of the results.

8. LINKS TO EXTERNAL PROJECTS

8.1 Cooperation with External Projects and Programs

MOSAiC will maintain close cooperation with a number of programs and other activities occurring on a similar time frame. The WMO-WWRP Polar Prediction Projects Year of Polar Prediction (YOPP) activity will provide a key opportunity for coordination with enhanced observing and modeling activities during the MOSAiC period. Coordination with YOPP will be particularly important for operational modeling, assimilation of MOSAiC data into operational models, coupled system model evaluation and development, and large-scale model analyses. Well-developed cooperation also exists with the Norwegian N-ICE project, the Japanese Arctic Challenge for Sustainability (ArCS) project, the International Arctic Systems for Observing the Atmosphere (IASOA) network of land-based atmospheric observatories, the German Transregional project “Arctic Amplification: Climate relevant atmospheric and surface processes and feedback mechanisms (AC)3”, and the Russia research programs on Cape Baranov, Tiksi and Spitsbergen.

We will establish contacts to successful proposal of the EU call BG-09 for an integrated Arctic Observing System. We do expect significant developments (science, technology, stakeholder interaction) and improvements in coordination as results from this project, even before the start of MOSAiC.

Arctic CORDEX is a WCRP and CliC sponsored initiative to advance and coordinate the science and application of Arctic regional climate downscaling through global partnerships. Among others the CORDEX goal is to produce coordinated sets of regional downscaled projections worldwide and to foster communication and knowledge exchange with users of regional climate information.

A special strength of MOSAiC is the intense collaboration with non-European partners. The goal of the “Transatlantic Ocean Research Alliance” as defined in the Galway Statement on Atlantic Ocean Cooperation is to work together in order to better understand and "increase our knowledge of the Atlantic Ocean and its dynamic systems - including interlinks with the portion of the Arctic region that borders the Atlantic" and to promote the sustainable management of its resources.

8.2 Cooperation with Parallel Experiments

MOSAiC will not only be connected to other vessels through the resupply (Section 4.3), but also have scientific and logistic collaboration with other experiments and expeditions during, immediately before and after MOSAiC. Direct collaboration with other activities will occur via specific agreements (where applicable) or via “endorsement” by MOSAiC. The endorsement process required a certain exchange of information with the potential participating group and an agreement about sharing data across programs. The extent to which MOSAiC resources are impacted by a collaborating project must be outlined in the endorsement agreement. Generally the MOSAiC data management structure will not be responsible for oversight of data from partner programs; however, links and cross-referencing of data will be essential to support value-added and collaborative research.

Science

Scientific measurements at MOSAiC and on the external vessels will be coordinated through direct contacts between the cruise leaders and individual scientists. It is planned to coordinate different ways directly through identical methods and sensors, but also though complementary measurements, which are not planned for MOSAiC. These measurements will allow larger regional coverage as well as an intensification of certain observations and measurements. Also the installation and maintenance of the distributed network may be supported by vessels in the vicinity.

Examples of already known and planned cooperation:

- Radio soundings will be coordinated with other ships in the vicinity, e.g. Mirai (Japan).
- Tara (France) is planning a new transpolar drift between 2019 and 2021. Their program will have a strong connection to the MOSAiC drift.
- Some scientific measurements will also be possible on the supply vessels, depending on their respective programs
- Ice chamber experiments (UEA, GB) for instrument testing and replicating conditions of interest experienced before or during the MOSAiC cruise in a controlled environment.
- Chinese plans: Parallel drift in Beaufort Gyre in 2020 and deployment of autonomous network at MOSAiC starting position in autumn 2020.

Beyond the collaboration with individual cruises, MOSAiC will play a central role in internationally coordinated programs as the IAOOS and the International Arctic Buoy Program.

Logistics

Different national Arctic expeditions in 2019 and 2020 will be directly linked to MOSAiC. These expeditions will carry out complementary measurements in other regions of the Arctic, and partly even in close proximity. Some are likely to support the deployment, re-deployment, and/or recovery of parts of the distributed network.

We will link the measurements of MOSAiC with various airborne campaigns that will most likely be performed during the drift. Most campaigns will focus in spring/summer 2020, e.g. starting from Longyearbyen (Svalbard), Station Nord (Greenland), or Alert (Canada). During spring, we plan to establish a runway close to Polarstern (Sections 3.2 and 3.5). This runway may be used for landing (and refueling) at Polarstern.

9. APPENDIX

9.1 Preliminary Tables of Parameters for each Section 2.1 to 2.5

Measurement frequencies relate to the main time series. In many cases, more frequent measurements and observations are planned for key parts of the year.

Atmosphere (see Section 2.1)

TABLE 9.1: Atmospheric variables measured during MOSAiC.

	Method	**Ice camp & PS**	**Distr. Network**	**>20 km**
Atmospheric State				
Surface meteorology	Weather stations, AWS	continuously	Continuously, at multiple nodes	Via partners (i.e. SOA)
Temperature moisture profiling	radiosonde	6-hourly		
	dropsonde			IOP aircraft measurements
	Raman lidar, microwave radiometer, IR spectrometer	continuously		
	UAV-based met sensor		Periodically	
Wind profiling	radiosonde	6-hourly		
	Doppler lidar, radar wind profiler, sodar	continuously		
Atmospheric turbulence	Doppler lidar, radar	continuously		
	Gust probe			IOP aircraft measurements
ABL height	Sodar, Doppler lidar	continuously		
Ozone profiles	ozonsonde	weekly		
Surface Fluxes				
Broadband radiation	PIR, PRP, PSP, SPN	Continuously, with redundancy	Continuously, at multiple nodes	
	Broadband suite			IOP aircraft measurements
Spectral and narrow-band radiation	AERi, MFRSR	continuously		
	Solar spectral radiation			IOP aircraft measurements
Turbulent heat and momentum fluxes	Meteorological tower, sonic, licor	Continuously at multiple levels	Continuously, single-level at multiple nodes	

	UAV-based sensors		Periodically	
Gas fluxes (CO2,CH4,O3,DMS)	Meteorological tower and chamber measurements	Continuous, and episodic as specific locations		
Clouds				
Vertical profiles, macrophysics, microphysics	Cloud radar, lidar, ceilometer, total sky imager, IR sky imager	continuously		
In situ samples	Cloud probes	Periodic		IOP aircraft measurements
	Fog samples	Periodic		
Spatial distribution	Scanning cloud radar	Semi-continuous		
Integrated properties	Microwave radiometer	Continuously, with redundancy		
Precipitation				
Rate / mass accumulation	Disdrometer, weighing gauge	continuously		
Snow depth	Sonic snow depth	continuously	Continuously at multiple nodes	
Spatial distribution	Scanning precipitation radar	Semi-continuous		
Particle images	In situ particle sensors	Continuously		
Water isotopes	spectrometer	continuously		
Aerosols/Gases				
Radiative properties	Sun photometer, MFRSR, optical depth sensor, nephelometer, PSAP, filters	continuously	Continuously at >= one node	IOP aircraft measurements
Profile information	HSRL lidar	continuously		
	Tethered balloon	periodic		
Physical properties	CPC/UCPC, SMPS, APS, UHSAS, HTDMA, fluorescent particle counter, filters/impactors	continuously		
	??			IOP aircraft measurements
Cloud activity	CCN, INP, filters	continuously		
Composition	ACSM, APi-L-TOF, ion spectrometer, mass	continuously		

	spectrometer, gas chromatography, filters/impactors, SP2			
Gases	O3, CO, N2O, CO2, CH4, CO, NOx, SO2	continuously		
	????			IOP aircraft measurements

Sea ice and snow (see Section 2.2)

TABLE 9.2: Sea ice variables measured during MOSAiC.

	Method	**Central Observatory**	**Distributed Network**
Sea Ice			
Thickness and mass balance	EM, airborne + ground	weekly	weekly (not in darkness)
	Drillings	weekly	None
	Buoys	continuously	continuously
	Multibeam sonar (ROV+AUV)	weekly	none
	Stakes & hot wires	weekly	none
Topography, surface + bottom	Laser scanning, airborne + ground	weekly	weekly (airborne only)
	ROV & EM	weekly	weekly (airborne only)
Freeboard	Leveling	monthly	none
	High prec. pressure sensors	continuously	none
Density	Coring	weekly	none
Salinity	Coring	weekly	none
	Ice harp	continuously	none
O18	Coring	weekly	none
Texture	Coring	weekly	none
Porosity (ice & ridges)	ROV+EM, ground	weekly	none
Stress	Stress buoy	continuously	continuously
	High prec. GPS	continuously	continuously
Strength	Borehole jack	weekly	none
Floe size (distribution)	Camera surveys	none	weekly
Lateral melt / floe size	Camera surveys	days, seasonal	weekly
Snow			
Thickness	Survey lines	weekly	none
	Buoys	continuously	continuously
	Survey flights (radar)	weekly	weekly

		(not in darkness)	(not in darkness)
Grain size, density, stratigraphy, hardness, liquid water content, specific surface area, salinity	Snow pits	weekly	none
Snow water equivalent	Samples	events	none
Redistribution	Particle counters	continuously	continuously
	Laser scanning, airborne + ground	weekly	weekly (airborne only)
Temperature	Snow pits	weekly	none
	Thermistor strings	continuously	continuously
Surface roughness	Laser scanning, airborne + ground	weekly	weekly (airborne only)
Surface properties	Cameras	continuously	continuously
Melt ponds			
Depth, geometry, coverage	Surveys	probes, daily	none
	Laser scanning, airborne + ground	weekly	weekly (airborne only)
	Cameras, ground + on buoys	continuously	continuously
	Cameras, airborne	days	Days
Temperature, salinity	Profiles	days	none
Optics			
Irradiance, spectral	Stations + buoys	continuously	continuously
Albedo, spectral	Stations + buoys	continuously	continuously
	Transects	weekly to daily	none
Transmittance, spectral	Station / buoys	continuously	continuously
	Transects	weekly to daily	none
	ROV	weekly to daily	none
IOP, spectral	Station / buoys	continuously	continuously
	Profiling	days to daily	None
Impurities	Samples	weekly to daily	none
Others			
MW properties (L, Ku, Ka bands)	Scatterometer ground surveys	weekly	weekly (not in darkness)
	Station	continuously	none
Location	GNSS / GPS stations	continuously	continuously
Deformation	Ship Radar	continuously	none
	Airborne images	weekly	weekly (not in darkness)
Visible images	Cameras, time laps	continuously	continuously
	Airborne images	weekly	weekly (not in darkness)
IR images	Cameras, time laps	continuously	none

Ice conditions	Bridge observations	daily	none

Ocean (see Section 2.3)

TABLE 9.3: Oceanic variables measured during MOSAiC.

	Method	**Ice camp & PS**	**Distr. Network**	**>20 km**
Profiles (manually operated without data transmission)				
T/S (full-depth)	CTD/rosette	weekly		
Chl a fluorescence	Fluorometer / rosette	weekly		
CDOM/FDOM fluorescence	Fluorometer / rosette	weekly		
Dissolved oxygen	CTD / rosette	weekly		
(Nitrate)	Extra sensor / rosette	weekly		
Turbidity	Transmissometer / rosette	weekly		
Samples (full-depth)	CTD/rosette	weekly		
T/S (0-500 m)	Misc. CTD (e.g. MSS)	daily	daily or more frequent	events
Biooptical / chemical parameters (0-500 m)	Misc. CTD (e.g. MSS)	daily	events	events
Turbulence profiles (0-400 m)	MSS (incl. CTD)	8 h frequent / weekly	events	events
Inherent ocean optical properties (0-100 m)	A-sphere, ac-9	2 h / weekly	events	events
Horizontal velocity, vertical shear (0-1000 m, full-depth)	Different frequency ADCP (LADCP)	continuously / weekly		
Fully autonomous ice-tethered buoys				
T/S (profiles, under-ice point)	Ocean profiling systems (IAOOS, ITP /D-TOP under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily of more frequent	
Nitrate	IAOOS, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	

Chl a fluorescence	Ocean profiling systems (IAOOS /ITP / D-TOP, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
CDOM/FDOM	Ocean profiling systems (IAOOS /ITP / D-TOP, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
Dissolved oxygen	Ocean profiling systems (IAOOS /ITP / D-TOP, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
pH	IAOOS, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
PAR	Ocean profiling systems (IAOOS /ITP / D-TOP, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
T microstructure (turbulence)	IAOOS, AOFB	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
Velocity	ITP / AOFB, other under ice ADCP	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
Mobile vehicle surveys				
T/S	AUV, ROV		continuously (events)	events
Chl a fluorescence	AUV, ROV		continuously (events)	events
Dissolved oxygen	AUV, ROV		continuously (events)	events
T microstructure (turbulence)	AUV, ROV		continuously (events)	events

Bio-geo-chemistry (see Section 2.4)

TABLE 9.4: Bio-geochemical variables measured during MOSAiC.

	Method	**Ice camp & PS**	**Distr. Network**	**>20 km**
Bio-geo-chemistry system sea ice/snow				
Carbon cycle				
CO2	Chamber measurements.	Weekly to bi-weekly	events	events
CH4	Ice cores, sea water (discrete + underway), chamber measurements	Weekly to bi-weekly	events	events
CO	Ice cores, sea water	Weekly to bi-weekly	events	events
VOC	Ice cores, sea water	Weekly to bi-weekly	events	events
Sulphur cycle				
DMS, DMSP, DMSO	Ice cores, sea water, snow	Weekly to bi-weekly	events	events
Nitrogen cycle				
N2O	Ice cores, sea water (discrete + underway), snow	Weekly to bi-weekly	events	events
Halogens	Snow, sea water, ice cores	Weekly to bi-weekly	events	events
Mercury	Snow, sea water, ice cores	Weekly to bi-weekly	events	events
Natural radionuclides (7Be, 222Rn, 210Po)	Snow, ice cores	Weekly to bi-weekly	events	events
Surfactans, TEP, INP	Ice cores, water, snow	weekly to bi-weekly	events	events
Black carbon	Snow	weekly to bi-weekly	events	events
Mayor ions, Br/I	Snow	weekly to bi-weekly	events	events
Halogens (co-ATM)	Snow, ice, frost flowers	weekly to bi-weekly	events	events
SF6/CFC (co-OCE)	Sea water	weekly		
Dissolved O2 (co-OCE, co-ECO) Winkler				
Lower troposphere				

Ozone	Air-measurements	daily (winter, spring IOP)	events	events
Halogens	Air-measurements	daily (winter, spring IOP)	events	events
CH4, CO2, DMS	Flux measurements	weekly	events	
C, S, N cycle+ mercury				
Up to the halocline	CTD-Rosette	weekly		
Under ice water	Kemmerer bottle	weekly		
Melt ponds	Kemmerer bottle	summer IOP		

Ecosystem (see Section 2.5)

TABLE 9.5: Ecosystem variables measured during MOSAiC.

	Method	**Ice camp & PS**	**Distr. Network**	**>20 km**
Sea ice discrete sampling for physical, geochemical, and ecological properties	Ice coring and sectioning; melt ponds	weekly	opportunistically	seasonal / events
Macronutrients (nitrate, nitrite, ammonium, phosphate, silicic acid, DON, DOP)	Sea ice sections, direct under-ice water, water column 10 - 12 depth horizons, melt ponds[1]	weekly	opportunistically	seasonal / events
Fluorometric Chl a	Sea ice sections, direct under-ice water, water column 6 - 8 depth horizons, melt ponds[2]	weekly	opportunistically	seasonal / events
Pigment Biomarkers	2 High Performance Liquid Chromatography (HPLC)		opportunistically	Limited subset
Particulate carbon, nitrogen phosphorus, and biogenic silica (POC, PON, POP, BSi)	1	weekly	opportunistically	Limited subset
Carbonate chemistry (TA, DIC)	2	weekly	opportunistically	Limited subset
Primary productivity – ^{14}C-bicarbonate tracer approach; radioisotope	2 24hr incubation period	weekly	opportunistically	Limited subset
Primary productivity – ^{13}C-bicarbonate tracer approach; stable isotope	2 24hr incubation period	weekly	opportunistically	seasonal / events
Photophysiology of autotrophs	Subset of 1; Fast repetition rate fluorometry (FRRF)	weekly	opportunistically	n/a

Net community production (NCP); seawater intake ~13 m depth	MIMS; O2/Ar measurements	continuously	n/a	n/a
Autotrophs; abundance, diversity	2 Light microscopy; Imaging Flow Cytobot (IFCB); Flow cytometry (FCM)	weekly	opportunistically	Limited subset
Bacterial productivity; ^{3}H-leucine tracer addition approach	2 Hours-long incubation period	weekly	opportunistically	Limited subset
Dissolved organic carbon, characterization of dissolved and colored organic matter, and (DOC, DOM, CDOM)	1	weekly	opportunistically	Limited subset
Meiofauna / Microzooplankton abundance, diversity, and biomass	2 Ring nets LOKI ROV Net	weekly	n/a	Ring nets - seasonal / events
Macrozooplankton / polar cod abundance, diversity, and biomass	2 Multinet Midi LOKI ROV Net	weekly	n/a	ROV net - seasonal / events
Ecosystem -omics; Use DNA and RNA to target protistan & prokaryotic diversity, relative abundance, and gene expression patterns;	2 Sampling results in MOSAiC-wide data sets for bacteria and archaeal 16S & protistan 18S amplicon libraries; both prokaryotic and eukaryotic meta-genomic & -transcriptomic libraries	weekly	opportunistically	Limited subset; DNA only - seasonal / events
Nitrogen assimilation rate measurements: 15N-Nxx tracer addition approaches - nitrate, ammonium, DON	2	2x month	n/a	Limited subset seasonal / events
Particulate organic matter export flux measurements (sinking POM); long-term-traps	Vertical profile; 3 depth horizons TBD; deployment time > 1 week	monthly	opportunistically	n/a
Particulate organic matter export flux measurements	Vertical profile; 3 depth horizons TBD;	2x month	opportunistically	seasonal / events

(sinking POM); short-term-traps	deployment time < 1 week			
Oceanic particle size spectra and distributions; Underwater Vision Profiler (UVP)	UVP - Continuous vertical measurements with rosette package	weekly	opportunistically	seasonal / events
Coordinated, cooperative experiments; rate change measurements – carbon, nitrogen cycling processes; light perturbation responses; nutrient perturbation responses; trophic top-down controls on carbon, nitrogen recycling processes	Limited depth horizons; bottom sea ice section, and select pelagic depth horizons; daily to weekly duration	2x month; rotating schedule	n/a	TBD
Gliders (O2, CDOM fluorescence, microstructure (T,S)	Under ice deployment of autonomous devise		opportunistically	seasonal / events

9.2 Preliminary Table of Partners

The following institutes/partners are currently involved in MOSAiC. This list is not complete yet and additional partners are highly welcome. The table is sorted by nation and institute abbreviation.

TABLE 9.6: Partners of MOSAiC sorted by nation and institute abbreviation.

International Organization / Institute	
ARICE	Arctic Research Icebreaker Cons.
ECMWF	European Centre for Medium-Range Weather Forecasts
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
IASC	International Arctic Science Committee
ICSU	International Council for Science
Belgium	
ULB	Université Libre de Bruxelles
UOL	University of Liège
Canada	
UCalgary	University of Calgary
UOM	University of Manitoba
UVictoria	University of Victoria
UWaterloo	University of Waterloo
York	York University
China	
PRIC	Chinese Polar Research Institute
TIO	Third Institute of Oceanography
Denmark	
AU	Aarhus University

DMI	Danish Meteorological Institute
Finland	
FMI	Finish Meteorological Institute
UH	University of Helsinki
France	
LATMOS/Sorbonne Université	Laboratoire Atmosphères, Milieux, Observations Spatiales at Sorbonne Université
LOCEAN/Sorbonne Université	Laboratoire d'Océanographie et du Climat at Sorbonne Université
LSGE	Laboratoire de Glaciologie et Géophysique de l'Environnement
MIO	Mediterranean Institute of Oceanography
LaMP	Laboratoire de Météorologie Physique Clermont-Ferrand
Germany	
AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
DLR	Deutsche Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DWD	Deutscher Wetter Dienst (German weather service)
GEOMAR	GEOMAR
JGU	Johannes Gutenberg University Mainz
MARUM	Center for Marine Environmental Sciences, University of Bremen
TROPOS	Leibniz Institute for Tropospheric Research
TUB	Technische Universität Braunschweig
UHB	University Bremen
UHH	University of Hamburg
ULeipzig	University of Leipzig
UTR	University of Trier
Great Britain	
BAS	British Antarctic Survey
HWU	Heriot-Watt University
NERC	National Environment Research Council
NOC	National Oceanography Centre, Southampton
NorthumbriaU	Northumbria University
SAMS	Scottish Association for Marine Science
UB	University of Bangor
UCL	University College London
UEA	University of East Anglia
UL	University of Leeds
UW	University Warwick
Japan	
HU	Hokkaido University, Cooperative Institute for Research in Environmental Sciences
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
NIPR	National Institute of Polar Research
UTokyo	University of Tokyo
Netherlands	
IMAU	University of Utrecht, Institute for Marine and Atmospheric Research
UG	University of Groningen, Groningen Institute for Evolutionary Life Sciences

Norway	
MetNo	Norwegian Meteorological Institute
NPI	Norwegian Polar Institute
UiB	Universitetet I Bergen
UiT	Universitetet i Tromsø
UTrond	University Trondheim
Poland	
IOPAN	Institute of Oceanology Polish Academy of Science
USA	
ARM	Atmospheric Radiation Measurement Facility
CIRES	Cooperative Institute for Research in Environmental Sciences
CRREL	Cold Regions Research and Engineering Laboratory
CU	University of Colorado
DOE	Department of Energy
DU	Dartmouth University
FIU	Florida International University
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NPS	Naval Postgraduate School
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
OSU	Oregon State University
TAMU	Texas A&M University
UAF	University of Alaska Fairbanks
URI	University of Rhode Island
UWA	University of Washington
WHOI	Woods Hole Oceanographic Institute
Russia	
AARI	Arctic & Antarctic Research Institute
MSU	Moscow State University
Shirshov	Shirshov Institute Moscow
Zuev IAO	V.E.Zuev Institute of Atmospheric Optics Tomks
Spain	
ICM	Institute de Ciencias del Mar
Sweden	
UOG	University of Gothenburg
Switzerland	
EPFL	École Polytechnique Fédérale de Lausanne
PSI	Paul Scherrer Institute, Villigen

9.3 Lists of Abbreviations / Acronyms

Methods / Instruments

TABLE 9.7: Abbreviations for methods and instruments.

AABC-Acoustic POPE	Arctic ABC, POPE
AABC-Autonomous Weather Station	Arctic ABC, Autonomous Weather Station
AABC-Environmental POPE	Arctic ABC, Environmental POPE
AABC-SIMBA	Arctic ABC, Sea-Ice Mass Balance (FMI)
ADCP	Acoustic Doppler Current Profilers
AHRS	RTK GPS / AHRS buoy
AIRS	Atmospheric Infrared Sounder
ALOS-2	Advanced Land Observing Satellite 2
AMSR(-E/2)	Advanced Microwave Scanning Radiometer
AMSU-A	Advanced Microwave Sounding Unit–A
AOFB	Arctic Ocean Flux Buoy
ASFS	Atmospheric Surface Flux Station
ATB	Acoustic Tomography Buoy
ATSC	Autonomous upper ocean Temperature and Salinity chain
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
AWS	Automatic Weather Station
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
COSMO-SkyMed	Constellation of Small Satellites for Mediterranean basin Observation
CERES	Clouds and the Earth's Radiant Energy System
CS2	CryoSat-2
D-TOP	Drift-Towing Ocean Profiler
EarthCARE	Earth Clouds, Aerosols and Radiation Explorer
GC	Gas chromatography
GNSS	High-resolution GPS buoy
GOME-2	Global Ozone Monitoring Experiment–2
GOSAT	Greenhouse gases observing satellite
GPSB	GPS buoy (high and low resolution)
HEM	Helicopter Electro Magnetics
HIRHAM	High Resolution Hamburg Model
IC	Ice Lander
IMB	Ice Mass Balance Buoy
ITBOB	Ice-tethered Bio Optical Buoy
ITM	Ice-tethered Microprofiler
ITP	Ice-tethered Profiler
ITSB	In-ice Thermistor String buoy
LOKI	video-optical casts
Lab	Laboratory
MODIS	Moderate Resolution Imaging Spectroradiometer

MetOp	Meteorological Operational Satellite
MHS	Microwave Humidity Sounder
MS	Mass spectrometry
NAOSIM	North Atlantic Arctic Ocean Sea Ice Model
NAVB	Navigation Buoy
NWP	Numeric weather prediction
OCO-2	Orbiting Carbon Observatory 2
OLCI	Ocean and Land Colour Instrument
PAA	Passive Acoustics Array
PT-RMS	Proton-Transfer Mass Spectroscopy
RadCI	RADARSAT Constellation Mission
RCM	Regional climate model
ROV	Remotely Operated Vehicle
RV	Research vessel
S-IMB	Seasonal Ice Mass Balance Buoy
SAOCOM	Satélite Argentino de Observación Con Microondas
SAR	Synthetic Aperture Radar
SARAL	Satellite with ARgos and ALtiKa
SB	Snow Buoy
SLSTR	Sea and Land Surface Temperature Radiometer
SMAP	Soil Moisture Active Passive
SMOS	Soil Moisture Ocean Salinity
SRAL	SENTINEL-3 Ku/C Radar Altimeter
SRS	Surface Radiation Station
SSMIS	Special Sensor Microwave Imager/Sounder
SVP	Surface Velocity Profiler
TB	Tethered Balloon
UAV	Unmanned Aerial Vehicle
UTB	Up-Temp-O Buoy
VIIRS	Visible Infrared Imaging Radiometer Suite
WB	Wave / tilt buoys , Ridge/wave buoys
WRF	Weather Research and Forecasting Model

Projects / Programs

TABLE 9.8: Abbreviations for Projects and Programs.

(AC)^3	Arctic Amplification: Climate Relevant Atmospheric and surface processes and Feedback Mechanisms
AMAP	Arctic Monitoring and Assessment Programme
ArCS	Japanese Arctic Challenge for Sustainability
ARM	US DOE Atmospheric Radiation Measurement Program
ASSW	Arctic Science Summit Week
BMBF	Bundesministerium für Bildung und Forschung
CliC	Climate and Cryosphere
CORDEX	Coordinated Regional Climate Downscaling Experiment

DFG	Deutsche Forschungsgemeinschaft
EPP	Environmental Prediction Plan
ESSD	Earth System Science Data
IAOOS	Ice-Atmosphere-Arctic Ocean Observing System
IASOA	International Arctic System for Observing the Atmosphere
ICARP III	Third International Conference on Arctic Research Planning
ISDAC	Indirect and Semi-Direct Aerosol Campaign
MPACE	Mixed-Phase Arctic Cloud Experiment
OAI-PMH	Open Access Initiative – Protocol for Metadata Harvesting
SHEBA	Surface Heat Budget of the Arctic Ocean
TIB	Technische Informationsbibliothek Hannover
WCRP	World Climate Research Programme
WDS	World Data System
YOPP	Year of Polar Prediction

Trace gases and chemical components, measured variables

TABLE 9.9: Abbreviations for trace gases, chemical components and measured variables.

Ar	Argon
BC	Black carbon
Be	Berillium
BSi	Biogenic Silica
C	Carbon
CDOM	Colored dissolved organic matter
CFC	Chlorofluorocarbon
CH4	Methane
Chl	Chlorophyll
CO	Carbon monoxide – Conflict with Central Observatory
CO2	Carbon dioxide
CTD	Conductivity Temperature Depth
DIC	Dissolved inorganic carbon
DMS	Dimethylsulphide
DMSP	Dimethylsulfoniopropionate
DNA/RNA	Deoxyribonucleic acid / Ribonucleic acid
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
INP	Ice nucleating proteins
N2O	Nitrous oxide
NOx	Nitrogen oxide
O/O2	Oxygen
Po	Polonium
POC	Particular Organic Compounds
PON	Particular Organic Nitrate
Rn	Radon
S	Salinity

SF6	Sulfur hexafluoride
T	Temperature
Tout	Temperature outside
TEP	Transparent exopolymer particles
VOC	Volatile organic compound

Others

TABLE 9.10: Other abbreviations within this manuscript.

ABL	Atmospheric boundary layer
BGC	Bio-geo-chemical
BHV	Bremerhaven
DMP	Data Management Plan
DOI	Digital Object Identifier
ECV	Essential climate variable
IOP	Intensive Observing Period
LES	Large-Scale Eddy Simulations
LYR	Longyearbyen
MCA	MOSAiC Central Archive
NRT	near real time
O2A	Observation to Archive
PDF	Probability density function
RDIF	raw data ingest framework
SCM	Single column model
U	University