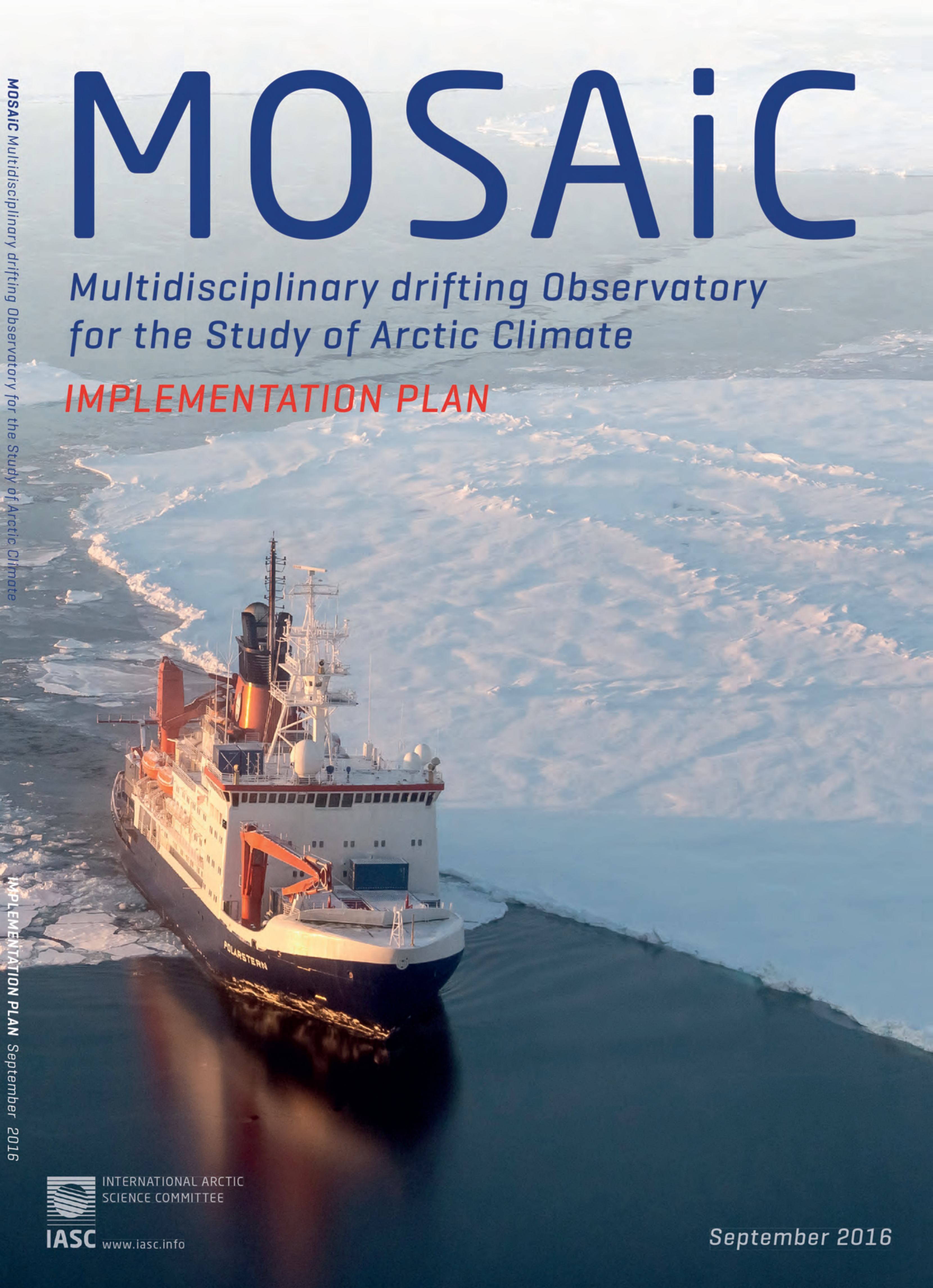
MOSAiC

Multidisciplinary drifting Observatory for the Study of Arctic Climate

IMPLEMENTATION PLAN



MOSAiC Multidisciplinary drifting Observatory for the Study of Arctic Climate

IMPLEMENTATION PLAN September 2016

INTERNATIONAL ARCTIC SCIENCE COMMITTEE

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SUMMARY

This document is the first 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 for how associated observational, modeling, synthesis, and programmatic objectives can be manifested. Implementation planning occurred via an international workshop in Potsdam in July 2015, and through two further smaller workshops in December 2015 and February 2016 at AWI Potsdam that have helped to formulate this document that will serve as a first step for implementation of this international endeavor. 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 project logistics, developing scientific observing teams, organizing scientific contributions, coordinating the use of resources, and ensuring MOSAiC's legacy of data and products. For context, a brief overview and summaries of key science drivers are provided in the remainder of 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. Plans for interfacing with satellite programs and model activities are given in Sections 5 and 6. The MOSAiC data management plan 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 September 2016. 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 ON MOSAiC

Changes in the Arctic sea ice system as a result of Arctic amplification have substantially affected Arctic regional weather and climate, and are globally relevant. To understand how these local and regional changes are unfolding and how they interact with, and affect, the weather and climate of the Northern Hemisphere is a major challenge. The basis of this challenge resides in the nonlinear dynamics of the coupled climate system that involves the atmosphere, ocean, sea ice, bio-geochemical cycles and feedbacks with the ecosystem. These coupled system processes manifest on many different spatial and temporal scales ranging from local processes in the Arctic (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 that a dearth of observations in the Central Arctic inhibits a sufficient understanding and model representation of the complex Arctic system. Observations related to cloud properties, surface energy fluxes, aerosols, boundary layer structure, thin sea ice dynamics, snow on sea ice, ocean stratification, gas transfer, biological feedbacks with ice and ocean, and others have been rare in the Central Arctic, especially over the course of a full annual cycle and in a coupled fashion. To understand the evolving state of the Arctic system, and the role it plays in a changing global system, requires detailed observations and improved representation of these central Arctic 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-Institut/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.

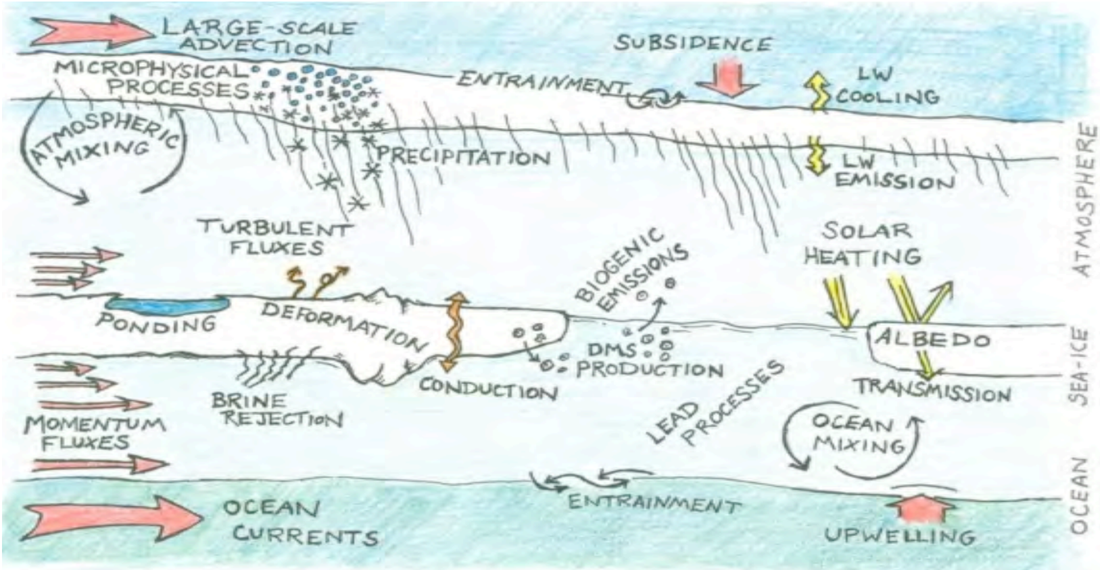

Fig. 1.2: Illustration of the interaction of the manifold processes between the different spheres of MOSAiC. (Figure: M. Shupe).

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 the flux of carbon, oxygen, and other important elements - in terms of the MOSAiC integrated observations -, particularly in the polar night?
- Which key groups and species mediate these fluxes, and what are the physical and biological processes that control their presence and activity?
- Which special adaptations assist organisms to survive in highly variable and/or intensely harsh environmental conditions?

Biological processes in the ice and ocean 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, elemental, and compound-specific cycles driven by biota. Our understanding of the Arctic is lacking year-round estimates of biological standing-stocks and elemental fluxes (e.g., carbon (C), nitrogen (N), and oxygen (O)), particularly for the polar night. Furthermore, we crucially need to develop knowledge on how the distribution and activity of those organisms driving elemental fluxes are driven by physical conditions (i.e., ice cover, stratification, distribution of water masses). Such physical-biological interactions directly impact production of C, N, and O, as well as pelagic retention, and vertical export of matter. In particular, the strength of the biological pump, which drives organic matter export from sea ice and the water column to the benthos, needs to be measured over the annual cycle. Dissolved organic carbon (DOC), which are poorly constrained despite their direct linkages to critical processes such as DMS production (above), nutrient recycling, and microbial food web dynamics also require further investigation. Biological productivity in the Arctic is often limited by the availability of nitrogen sources to primary producers. Therefore, another 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 required. Here, a detailed evaluation is needed regarding the seasonally varying role and balance between physically and biologically driven interactions between sea ice and the oceanic microbes, protists, and fauna.

Sea ice and under-ice biota play a crucial role in high-latitude ecosystems as valuable food sources fueling higher trophic levels in the Arctic. Measurements of sympagic and pelagic diversity, community structure, and biomass are necessary to fully 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. Experiments to quantify transformations of carbon and other essential elements will be conducted to constrain the rates at which these transformations can occur during episodic and seasonal events. Each of these parameters and rates are needed to employ state-of-the-art biogeochemical and climate modeling of a 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.

Ground validation for satellite remote sensing

- How well do satellite algorithms perform in the Central Arctic for processes such as sea ice thickness distribution, snow depth, and ice deformation?
- 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 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 depth, 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.

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.

The following sections summarize the disciplinary measurement requirements that are needed for MOSAiC to achieve its interdisciplinary science objectives. Requirements are referenced to different measurement domains including the Central Observatory (CO), distributed network, and 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.

A Central Observatory, based on 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 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. Periodic activities or IOPs will be conducted at targeted times of the year and will involve additional measurements and associated activities. 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. In addition, these tables will be significantly extended in the coming technical implementation plan.

2.1 Atmosphere

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 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 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 be planned, utilizing 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 period.

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 or tethered balloons.

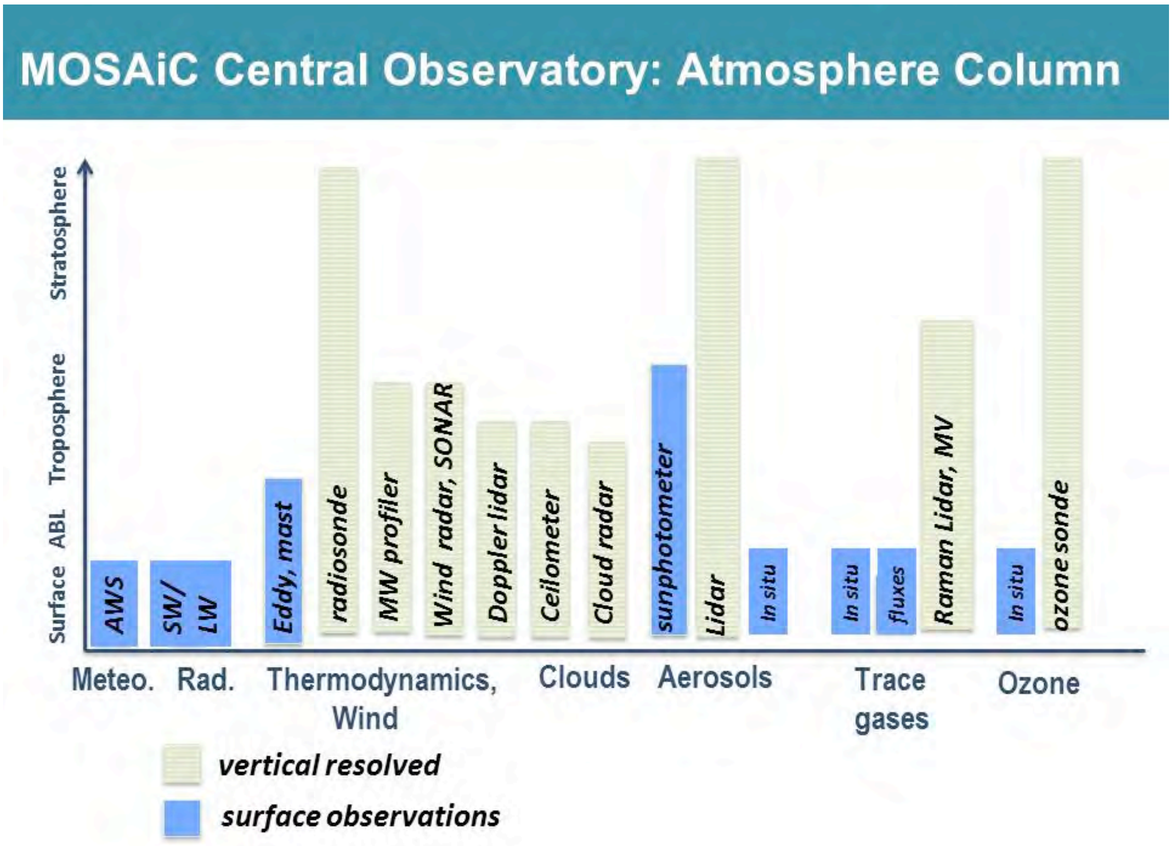

Fig. 2.1: Components and instrumentation for the measurement of the Atmosphere Column at the Central Observatory. (Figure: R. Neuber).

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 also be installed independently on top of the bridge and potentially 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, an inlet will be designed and installed to minimize 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 need to 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 and other obstructing installations, like generators. The "Met City" of the ice camp 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 likely not directly adjacent to the other on-ice atmospheric measurements.

Distributed network

A distributed network of meteorological observations is needed 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, 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 four of these remote atmospheric measurement stations, and potentially more, 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 will also be available 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 allow 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 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

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

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.

Work on Polarstern

Different, comparably small, installations are necessary on Polarstern in order to monitor the ice camp and the surrounding of the ship (visible and infrared cameras). 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.

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. Key elements are:

- Transects of sea ice thickness, snow depth, freeboard in order to obtain sea ice and snow mass balance
- Transects of optical properties, including spectral albedo and transmittance, in order to obtain sea ice and snow energy budgets and fluxes through the ice, and also to help characterizing sea ice as a habitat.
- Snow cover studies, widely spread over the ice camp, in order to quantify snow accumulation (and its history), as well as surface topography and redistribution.
- ROV based work in the uppermost meters of the ocean in order to investigate the ice-ocean interface with a focus on sea ice draft, radiative fluxes, and thermohaline structure.
- Sea ice and snow sampling from ice cores in order to describe the physical properties of the sea ice and the snow cover
- Investigations of surface properties and their changes (in particular in summer) with respect to roughness, melt processes and melt pond formation and evolution.
- Sea ice deformation (lead opening and ridging) events.

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 is the use of an Autonomous Underwater Vehicle (AUV), which may be used on a weekly base 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.

Possibilities of using a hovercraft for transect measurements within the distributed network are currently under discussion, but this platform would allow additional surveys of surface features and 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, as well as during winter, when helicopter operations will only seldom be possible.

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

Sea ice, snow and melt pond studies at a secondary ice camp will allow more intensive observations of spring-summer properties and processes away from Polarstern. This camp will allow studying the spring summer transition into the main melting season on different ice conditions and without the impact of Polarstern and the large ice camp. The secondary ice camp has the advantage of e.g. less drainage holes, undisturbed snow accumulation, less "dirt" on the ice (short-wave interaction). The ice camp will be directly connected to one of the main nodes of the distributed network.

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.

2.3 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

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 water sampling (CTD/Rosette) will be conducted throughout the expedition. The ships laboratory space and place for analyze-container is needed for installations instruments like gas chromatographs for trace gas measurements 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 daily/weekly sampling of snow and sea ice (ice cores) to measure the trace gases. We aim to do regular chamber measurements to determine the sea ice- air flux.

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).

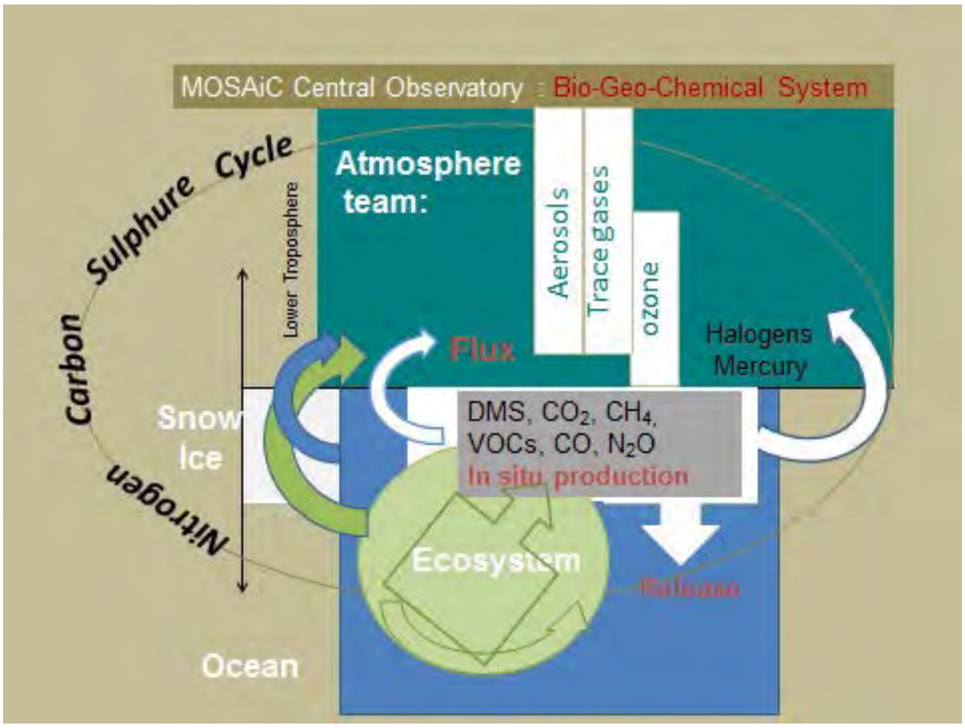

Fig. 2.2: Components for the measurements of the bio-geo-chemical system and links to atmospheric measurements (Figure: E. Damm).

2.5 Ecosystem

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 directional convection of elements to depth, a process known as the 'biological pump', but also exhibits strong controls on the cycling of climate-active gases such as CO2, CH4, N2O and dimethyl sulfide (DMS) near the atmosphere-ice-ocean interfaces. The mobilization of nutrients (e.g. via upwelling) critically depends on ocean physics, altogether calling for the establishment of high Arctic nutrient budgets and dynamics over the entire of the annual cycle.

High-latitude ecosystems that use sea ice as substrate, habitat, and a foraging ground are highly productive and can respond comparably quickly to external triggers like light, nutrient input, or grazing. However, the strength, timing, and net effects of these couplings on overall elemental 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.

Work on Polarstern

We envision near daily and weekly sampling for each of the 5 thematic sub-teams, supported by CTD casts. The following activities would be executed across daily rosters: 1) Ship-board sampling resolving incoming irradiance, inorganic nutrients, and particle concentration profiles (using UVP, LOPC or equivalent), 2) size-fractionated water samples for plankton biomass (chlorophyll a (Chl a), particulate organic carbon and nitrogen (POC, PON), Biogenic

Silica (BSi), and High Performance Liquid Chromatography (HPLC) to assess pigment composition). 3) primary production, nutrient uptake and cycling, and 4) sampling for molecular and microscopic characterization of microbes and larger biota, 5) net hauls, video-optical casts (LOKI), and continuous echosounding of large phytoplankton, zooplankton, and fishes. In addition, larger volumes of water would be collected for ship-board manipulation experiments to resolve rate processes, such as nutrient uptake and grazing.

Work on Ice camp

We aim to do a regular monitoring of the sea ice conditions year round using a range of technologies including deployment of towed bodies and ROVs with multiple optical sensors and sample collectors to obtain coverage on the scales of 10 m to several kilometers. In addition, ice cores will be collected to determine the key biogeochemical parameters crucial for radiative balance and biological processes (e.g., temperature, salinity, colored dissolved organic matter (CDOM), ice texture, nutrient concentrations, and species composition via microscopy and molecular methods). The ice camp will also be an important site to execute measurements of under-ice light profile throughout the polar winter away from the Polarstern´s light contamination. We will seek technologies able to resolve light intensities well below the lowest light levels currently known to support primary production, (<2 µmol photons m^{-2} s^{-1}). 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.

Distributed network

To understand the dynamics of the biological pump, export flux measurements will be carried out including moorings with short- and long-term sediment traps (location TBC). Water column sampling could support flux characterization, e.g. by using ^{234}Th as a tracer of vertical carbon flux. 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.

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 14CO2 and 13CO2 uptake rates, continuous O2/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 will be assessed using Leucine/Thymidine incorporation studies. Abundance of bacteria, phytoplankton, and zooplankton, as well as their species distribution will be addressed through flow cytometry, image recognition strategies (FlowCam), and microscopic analyses of discrete samples and melted ice cores. Where possible, an imaging flow cytobot will measure the pelagic abundance. phytoplankton. 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 prokaryotes and protists in sea ice and water samples mainly at the central observatory. Sea ice and water samples will be processed for size-fractionated measurements of plankton biomass (POC, PON, Chl a, pigments). POC and PON measurements will also yield natural abundance stable isotope data of 15N and, 13C. BSi and particulate phosphorus are other potential kay parameters that will be measured from the water column and sea ice. Organic matter cycling will be assessed by a number of measures including various measurements of DOC, 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.

Ecosystem 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.

3. OBSERVATIONAL SCALE AND SCIENTIFIC-TECHNICAL IMPLEMENTATION

The MOSAiC drift experiment, covering a full annual cycle from October 2019 to October 2020, is divided into 6 legs, starting in Tromsø, Norway, and ending in Bremerhaven, Germany. The expected drift will start in the Laptev Sea (e.g. 120°E/84°N) and follow the transpolar drift towards Fram Strait. More details about the drift and the schedule are described in Section 4.

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) will be the home of all MOSAiC participants during the drift. This section describes the necessary preparations and realizations on the vessel in order to enable the various measurement programs of all teams (Section 2.1 to 2.5).

Preparations before the drift

The wintering and the continuous observational program through the entire winter will require some particular preparations before departure to MOSAiC. 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:

- Additional winterizing:
  - The main CTD winch needs a cover that allows the operation of the winch and access to the ocean through the entire winter.

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). A detailed planning of the distribution of teams and instrumentation will start soon and be a central element of the coming technical implementation plan. This plan will base on good experience from interdisciplinary expeditions and their use of ship space, but also consider the particular requirements of long-term observations for MOSAiC. In addition, 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. Most labs are on E-Deck (see Figure 3.4), but additional rooms are available on A-deck, mostly used in connection to atmospheric and remote sensing or airborne related work.

Beyond installations in laboratories in the ship, antennas, cameras, and other samplers 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.

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 during the drift

In addition to the existing laboratories onboard Polarstern, a number of laboratory and storage containers are needed to accommodate the various needs of all teams on board. These containers include (see Table 3.1):

- 9 containers for atmospheric measurements with the need for unobstructed views of the sky
- 4 workshops
- 5 wet laboratories
- 8 dry laboratories, incl. an isotope and a freezer lab
- 2 refrigerator units for samples
- 9 storage containers at room or outside temperature
- 1 storage container heated outside

Fig. 3.1: Photo of Polarstern in sea ice with a helicopter taking of for a measurement survey. This image might help to illustrate the positions of decks and installations on board: E-Deck is the uppermost blue deck with the working deck, D-Deck the bottommost white deck, A-Deck directly under the bridge, and P-Deck (German: Peildeck) on top of the bridge. (Photo: M. Nicolaus).

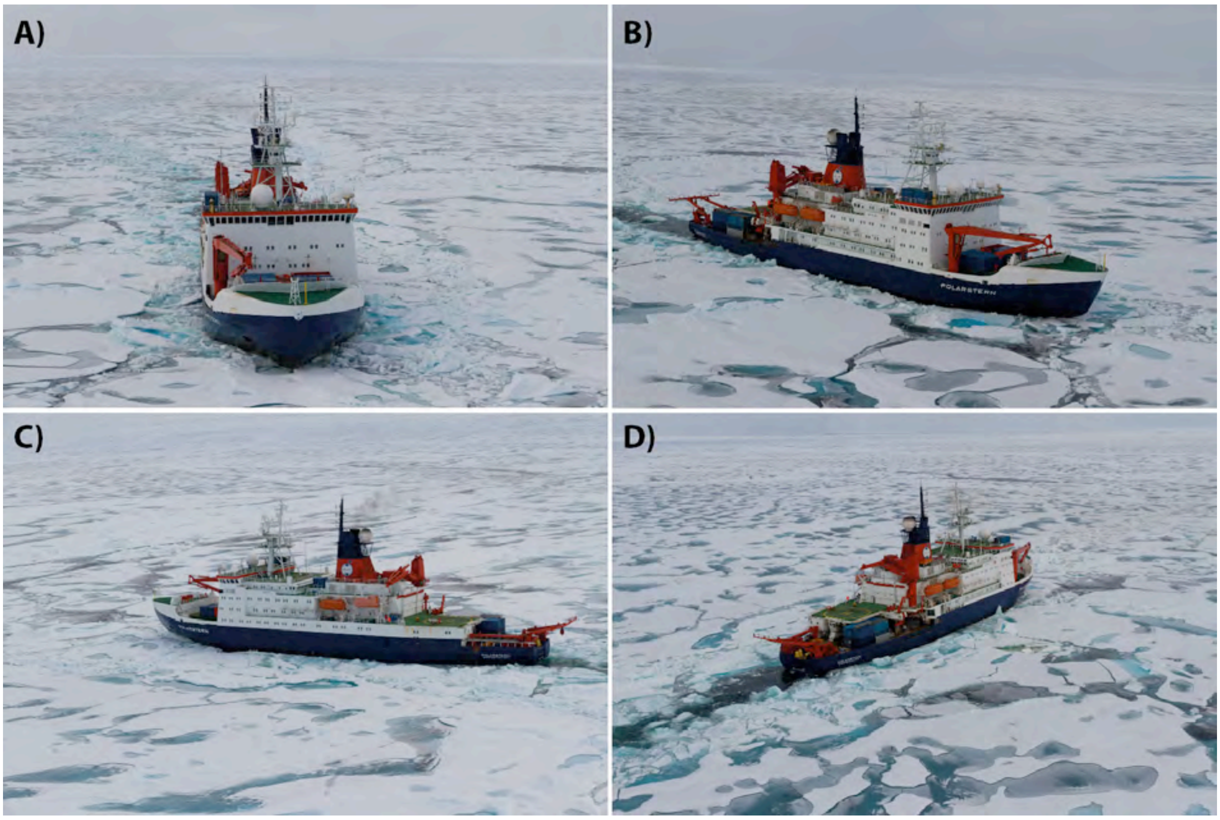

Fig. 3.2: Photos of Polarstern in sea ice from different perspectives. The photos illustrate the different decks, cranes, and possibilities for installation and storage. (Photos: M. Nicolaus).

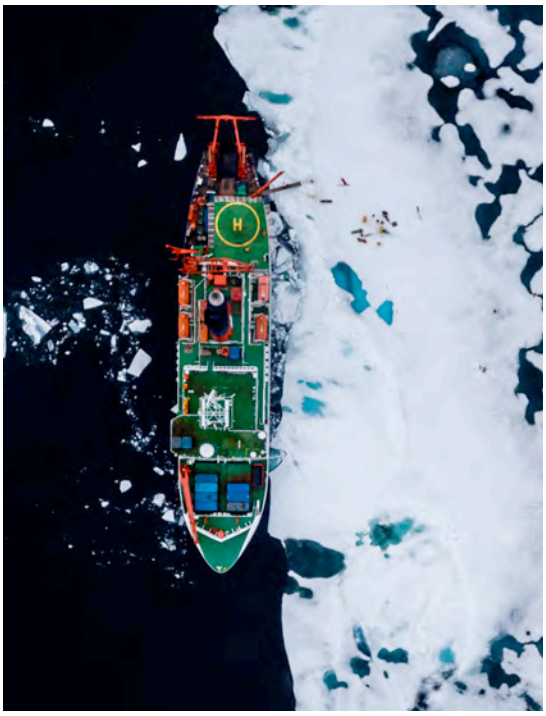

Fig. 3.3: Nadir photo of Polarstern on an ice edge. This image might help illustrate the positions of containers and installations on deck. In this case 7 containers (20") are carried on the bow and two smaller containers on the P-Deck (see also description in Figure 3.1). (Photo: S. Hendricks)

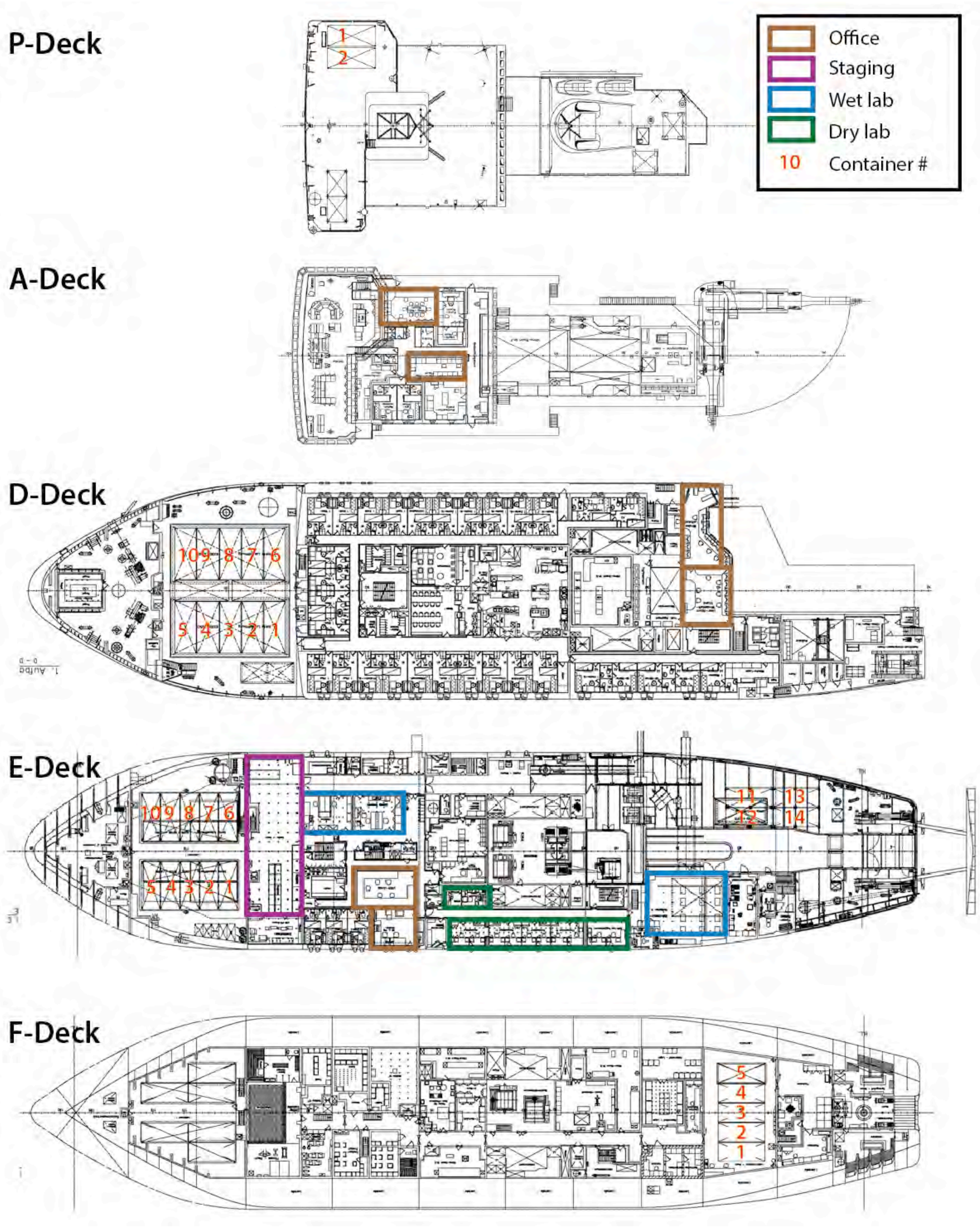

Fig. 3.4: Positions of scientific containers (laboratories, storage, workshops) and laboratories on the different decks of Polarstern. "Offices" may also include computers and electronics in a wider sense (e.g. registration units or instruments). P-Deck (not an official deck name) refers to the uppermost deck above the vessel's bridge. Numbers of containers refer to Table 3.1.

TABLE 3.1: Types: "Lab" needs electrical power, "WetLab" needs electrical power and water (in/out), "FreezerLab" needs electrical power, "Storage" no special requirements, "Storage temp" needs electrical power. T: Temperature, Tout: Outside temperature (=no temperature control), Tin: ship temperature. Letters in name indicate deck, see also Figure 3.4.

#	Usage	Institute (PI)	Type	Comment
P-Deck				
P1	Air chemistry	AWI (Weller)	Lab	
P2	FTIR	AWI / IUP	Lab	
D-Deck				
D10	OceanNet	TROPOS	Lab	
D9	ARM 3	DOE	Lab	
D8	ARM 4	DOE	Lab	
D7	ARM 5	DOE	Lab	
D5	Doppler Lidar	UTR (Heinemann)	Lab	
D4	ARM 1	DOE	Lab	
D3	ARM 2	DOE	Lab	
E-Deck Bow				
E1	Workshop Ozean	AWI (Kanzow)	Lab	
E2	Workshop HEM/ROV	AWI (Nicolaus)	Lab	
E3	Workshop AUV	TBD	WetLab	
E4	Freezer lab (-20°C)	AWI (Nicolaus)	FreezerLab	
E5	Science equipment	AWI	Storage	T=Tin
E6	Lab (non AWI)	TBD	Lab	
E7	Lab (non AWI)	TBD	Lab	
E8	Samples	AWI	Reefer	T=-5°C
E9	Samples	AWI	Reefer	T=-20°C
E10	Science equipment	AWI	Storage	Room temp.
E-Deck Working deck				
E11	Ice station instrum.	AWI	Storage (heat)	T>0°C
E12	Basic Lab	TBD	Storage	T=Tout
E13	Ice station instrum.	AWI	Storage	T=Tout
E14	Skidoos, sleds	AWI	Storage	T=Tout
Over E11	Logistics (garbage)		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				
F1	Isotopes	AWI	Isotope	
F2	Lab 1	AWI (Hoppe, Rost, Rokitta)	WetLab (temp controlled)	
F3	Lab 2	AWI	WetLab	
F4	Lab 3	AWI	WetLab	
F5	Lab 4	AWI	WetLab	

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 3.5). 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. Additional side arms of 100m length will allow power supply to additional sites. 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.

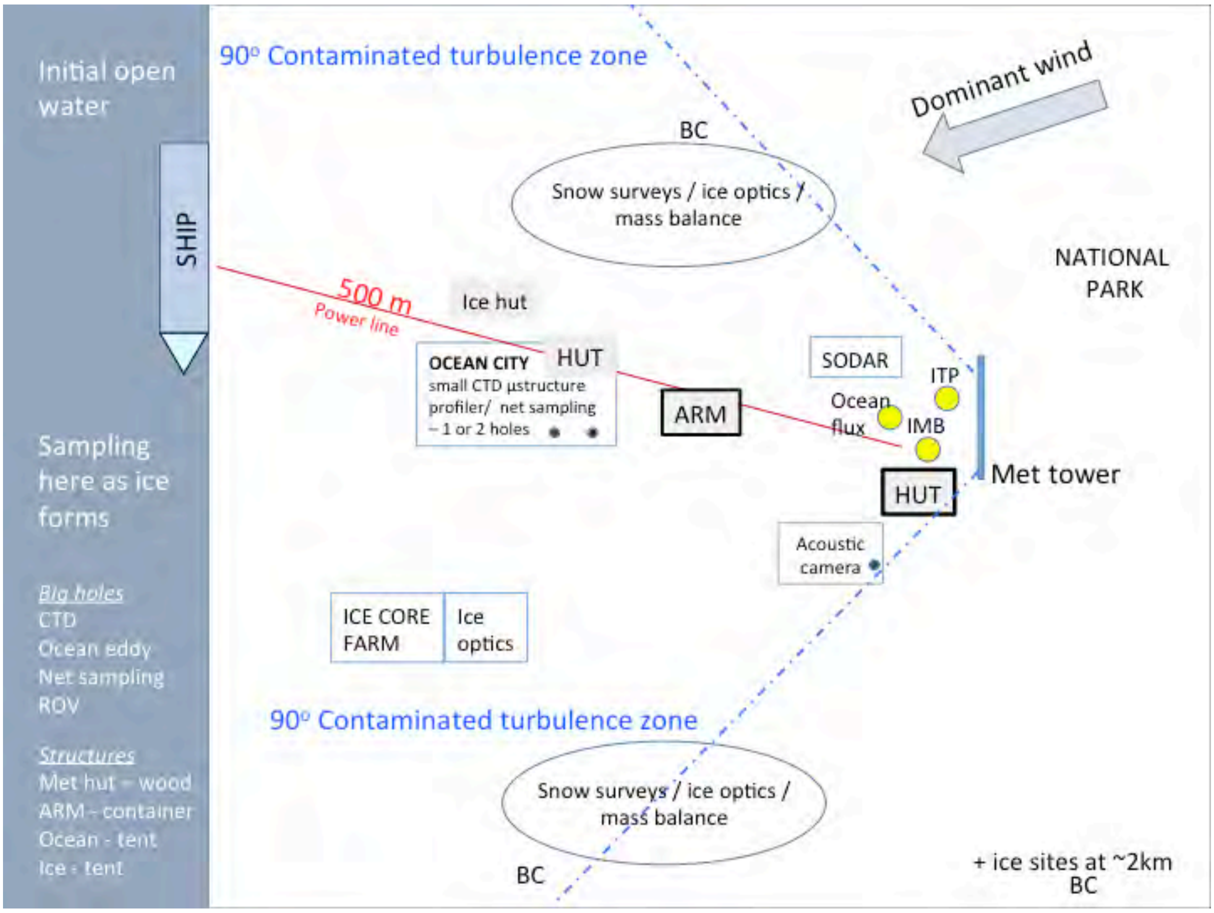

Fig. 3.5: Schematic of the different installations on the ice camp at the Central Observatory.

Installations in the main “cities”

- Met City (may be 2 of them on different ice conditions)
  - 2 huts for electronics controlling the continuous measurements
  - Permanent installations
    - 10-20m weather mast

        - Flux measurements: long-wave, short-wave, turbulence
        - Gas exchange fluxes
        - Sodars on the ice
    - Tethered balloon operations
    - No walk area
- Ocean City
    - 2 huts for electronics controlling the continuous measurements
    - 1 hut with open water access underneath for casts (down to 500m)
    - Permanent installations
        - Under-ice flux measurements
        - 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
- Gliders for scientific missions / need to discuss recovery scenarios in close ice cover.

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 by 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 3.6). This distributed network will be comprised of multiple sets of stations that contain distinct instrument suites to be deployed on distinct scales (see Figure 3.6). The primary station types are described in Table 3.2. The more complex supersites will include comprehensive, interdisciplinary measurements distributed approximately 15km apart at install. Medium sized sites will include primarily upper ocean and ice measurements over a denser network with ~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.

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 3.6. Specific platforms are described in more detail in Table 3.3.

Station Type	**Platforms, with measurements**
Super-site (S)	ITP / IAOOS (NOTE: IAOOS and ITP can be used interchangeably for ocean state profiles), IMB, GPSB, O-Buoy, AOFB, spectral Radiation, NAVB, SEBS, Some sites including sediment traps and water samples
Medium site (M)	ITM/UTB, IMB, GPSB, Some sites including sediment traps and water samples
IAOOS site (I)	IAOOS, NAVB
Position site (P)	GPSB
Mobile / throughout	Ocean glider (operating in hourglass pattern between sites S and PS / ice-camp)

Deployment and re-deployment

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 3.6. First the location for the Central Observatory will be determined and marked. Thereafter, the distributed network will be deployed using a combination of the Polarstern and other support vessel(s) as available. Support vessels could include the Russian Akademic Federov, Korean Araon, US Healy, or others. The focus at this initial deployment stage will be on the major installations, specifically the Supersites as these include buoys that are not well-suited to deployment without a ship. Once major installations have been completed the Polarstern will return to the Central Observatory location. Smaller network stations will be deployed during the following days from the Central Observatory using helicopter 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 re-deploying stations, likely in spring of 2020. If necessary these re-deployments will be conducted using helicopter, but 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.

TABLE 3.3: Platforms and measurements for the distributed network.

Name of Buoy / Platform	**Measurements**
Ice - Atmosphere - Arctic Ocean Observing System (IAOOS)	Ocean state, Chl-a, CDOM/FDOM, optical backscatter, nitrate or pH, dissolved oxygen, PAR, ice thickness, snow depth, ice T profile, surface meteorology (P, T, q, wind), Cloud presence, position
Ice Tethered Profiler (ITP, ITP-V)	Ocean state, Chl-a, CDOM/FDOM, optical backscatter, dissolved oxygen, PAR, position ITP-V includes velocity.
Ice Tethered Microprofiler (ITM)	Upper ocean state, position
Automatic Weather Stations (AWS)	Surface meteorology: air pressure, air temperature, wind, relative humidity, SW+LW radiation, floe rotation (compass)
Up-Temp-O Buoy (UTB)	Upper ocean temperature, surface pressure, position
Arctic Ocean Flux Buoy (AOFB)	Ocean momentum, heat, salt fluxes, position, horizontal velocity, acoustic backscatter – observations in the under-ice boundary layer and around 50 m depth (pycnocline)
Ice Mass Balance Buoy (IMB)	Sea ice thickness, snow depth, air/snow/ice T profile, visual imagery, position
Bio-physical buoys (ITBOB)	Transmitted solar flux, Nitrate, chlorophyll sensors, ADCP (here or somewhere else)
Automatic water samplers	Water samples
O-Buoy	CO_2, O_3, BrO, surface meteorology (P, T, q, wind), position
Surface Energy Budget Station (SEBS)	Surface meteorology (P, T, q, winds), broadband radiative fluxes, surface turbulent heat fluxes, position
Sediment traps	
Automatic water samplers	
GPS buoy (GPSB) (hi-res and lo-res)	position

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

Ocean Glider	Ocean state, temperature microstructure (turbulence), dissolved oxygen, Chl a fluorescence.
Navigation Buoy (NAVB)	Navigational buoys for glider operations
Autonomous Underwater Vehicle (AUV)	Physical and biological oceanography, sea ice bottom topography (multi beam sonar), energy fluxes

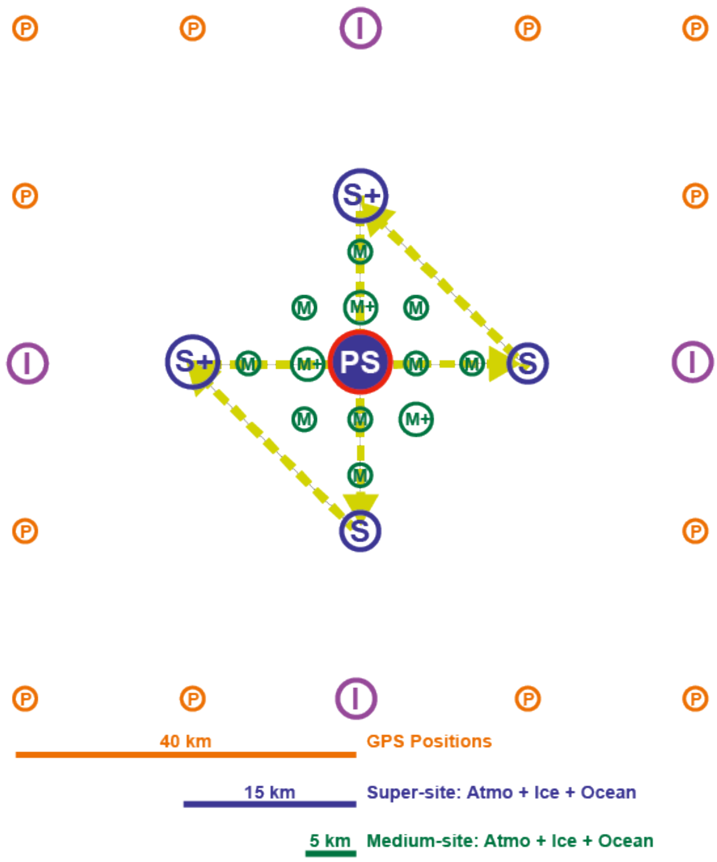

Fig. 3.6: The distributed network is arranged around the central observatory with Polarstern (PS) in the middle. It covers 3 additional scales: 5, 15, and >20 km. Different colors and letters refer to the list of autonomous devices (see Table 3.2). (Figure: M. Nicolaus)

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 Surface Energy Budget Stations (SEBS), 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 SEBS 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.

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.

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. 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

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)

It is envisaged to use UAVs of different size and purpose 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. 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

Tethered balloons may be operated for investigations of the atmospheric boundary layer (ABL). They can carry various types of scientific payloads of up to several kilograms in weight to altitudes of up to ~1500 m. However, most interesting for tethered balloon deployment will be the lower most troposphere, thereby allowing in situ measurements above the height of meteorological masts up into the lowermost range of remote sensing instruments like lidars. Tethered balloon operation will occur away from the ship at a dedicated location on the ice floe and can occur under low wind speeds only. In contrast, free flying balloons, like those carrying meteorological and ozone sensors will be launched from the ship during almost all weather conditions.

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 time and to be maintained until early summer. The runway needs to be at least 1200 m length to allow for landing of AWI’s Polar aircraft. Ice floe and runway conditions will follow regulations of the Canadian operator of the Polar aircraft. The aircraft can operate out of Longyearbyen, Spitsbergen or Alert, Canada. Typical ranges for such missions are shown in Figure 4.2.

In addition to transports, AWI’s Polar 5, 6 airplanes are expected to carry out scientific missions between Spitsbergen and the MOSAiC drift. These will be organized as part of IOPs and might require landings on the MOSAiC runway for refueling.

Russian helicopters operating from Cape Baranov on Bolshevik Island shall be used for personnel transport as long as RV Polarstern is within their range, see Figure 4.2.

Spring airborne campaigns: aircraft overflights

It is anticipated, that multiple aircraft campaigns will take place during the MOSAiC campaign; These will overfly the site without landing. Their activities shall be organized within IOPs, see chapter 3.5.

3.5 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. To facilitate IOPs it may be advantageous to establish a temporary ice camp, e.g. ~10km away from the Central Observatory and potentially near one of the super-sites in the distributed network. A remote camp would allow for measurements that 1) are significantly less impacted by the vessel and the Central Observatory camp activities, and 2) allow for intensive measurements on a different ice floe and/or part of the ice pack. For example, a remote camp could examine an extensive area of thin ice (all FYI), an area near a significant lead, or other characteristic conditions. The ideal time for such a camp would be end of April through early August (i.e., Legs 4 and 5), for easy coordination with personnel rotation schedules.

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.
- 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 additional 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 (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.
- Aircraft campaigns (April – October 2020): A variety of aircraft missions are possible, focused on surface and/or atmospheric properties. These are most likely during the spring into autumn of 2020 as the MOSAiC constellation should be moving into a domain that is accessible via aircraft missions out of Svalbard. 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 remote camp 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.
- Lead Processes (opportunistic): 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, ABL modification, surface gas exchange, ocean surface layer properties, ice formation processes, lateral ice melt, and other processes.
- Ridge Processes (opportunistic): 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.

4. PRACTICAL / LOGISTICAL ASPECTS

4.1 Detailed Time Line (2016-2022)

The current status of the schedule for MOSAiC is summarized in Table 4.4. This schedule corresponds to the optimal schedule and drift (i.e., plan A). It is planned to split the drift experiment into 6 legs of approximately 2 months duration. Leg 1 and Leg 6 are 2 weeks longer, because they include the transit to and from the drift floe. Leg 1 also includes the deployment of the distributed network and Central Observatory ice camp. 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. The exact start and end dates are also still to be defined and need to be coordinated with the shipyard and other expeditions' schedules. The current plan is to leave port in Tromsø on 01 October 2019 and to return to Bremerhaven by 31 October 2020. 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.

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	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
December 2017	Formalized agreements with funding agencies Formalized contracts with logistic support Formalized collaborations with MOSAiC partners
March 2018	Internationale Polartagung Rostock

	MOSAiC Science Conference
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

Drift schedule (Oct 2019 – Oct 2020)

The core element of the presented schedules is a full year of observation in the Central Arctic sea ice. This is envisaged from 18 October 2019 to 18 October 2020, requiring Polarstern to be anchored to the floe at least 3 days before and afterwards. The following calendar shows the split of the experiment into 6 legs. It could be necessary to extend the time legs and to reduce the number of refuelings.

TABLE 4.2: Timetable of the MOSAiC field experiment. Additional dates and actions for logistics and supply are described in Section 4.3.

Date	Week	Comment	Date	Week	Comment	Date	Week	Comment
27.09.19		End TransArc	07.02.20	16		26.06.20	36	Leg 5
01.10.19		Depart TOS	14.02.20	17	Resupply &	03.07.20	37	
		Install						
10.10.19		Network	21.02.20	18	Exchange	10.07.20	38	
15.10.19		Supply @Floe	28.02.20	19	Leg 3	17.07.20	39	
		Start time						
18.10.19	0	ser.	06.03.20	20		24.07.20	40	
25.10.19	1	Leg 1	13.03.20	21		31.07.20	41	
01.11.19	2		20.03.20	22		07.08.20	42	
08.11.19	3		27.03.20	23		14.08.20	43	Resupply &
15.11.19	4		03.04.20	24		21.08.20	44	Exchange
22.11.19	5		10.04.20	25	Heli Exchange	28.08.20	45	Leg 6
29.11.19	6		17.04.20	26	Leg 4	04.09.20	46	
06.12.19	7		24.04.20	27		11.09.20	47	
13.12.19	8	Heli Exchange	01.05.20	28		18.09.20	48	
20.12.19	9	Leg 2	08.05.20	29		25.09.20	49	
27.12.19	10		15.05.20	30		02.10.20	50	
03.01.20	11		22.05.20	31		09.10.20	51	
10.01.20	12		29.05.20	32		16.10.20	52	
17.01.20	13		05.06.20	33		18.10.20	53	End time ser.
24.01.20	14		12.06.20	34	Resupply &	21.10.20		Leaving the ice
31.01.20	15		19.06.20	35	Exchange	31.10.20		Arrive BHV

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.

TABLE 4.3: 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

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 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 2001 to 2013 (and into 2014). 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 4.1. Based on these simulations, the best-suited starting position is around 84°N and 120°E 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 do 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 Drift Forecast Experiment, see Section 6.1.

Figure 4.2 shows the average simulated drift track for a starting point at 84°N and 120°E. The drift track is 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.

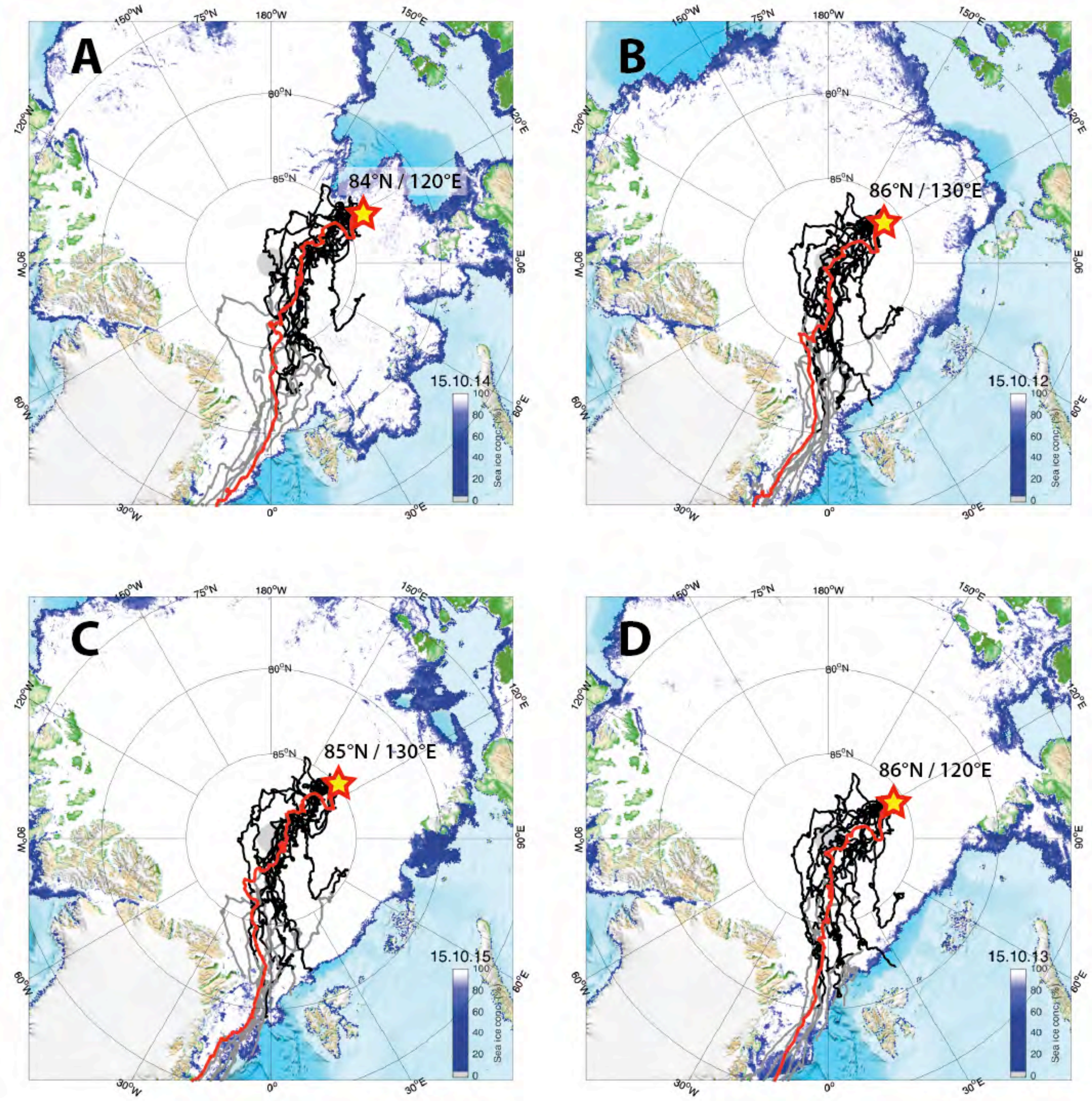

Fig. 4.1: Drift trajectories for selected starting positions (yellow stars) calculated for the years (2001 to 2013, and into 2014) assuming a start of the drift on 15 October. Grey trajectories give full drift, while black parts represent the drift within 1 year. The red trajectory highlights one selected, rather average drift year (2004). Different plates also represent different ice conditions for 15 October: a) in 2014, b) in 2012 (the minimum extent year), c) in 2015, and d) in 2013. Starting positions are given as coordinates. (Simulations: T. Krumpen, Figure: M. Nicolaus)

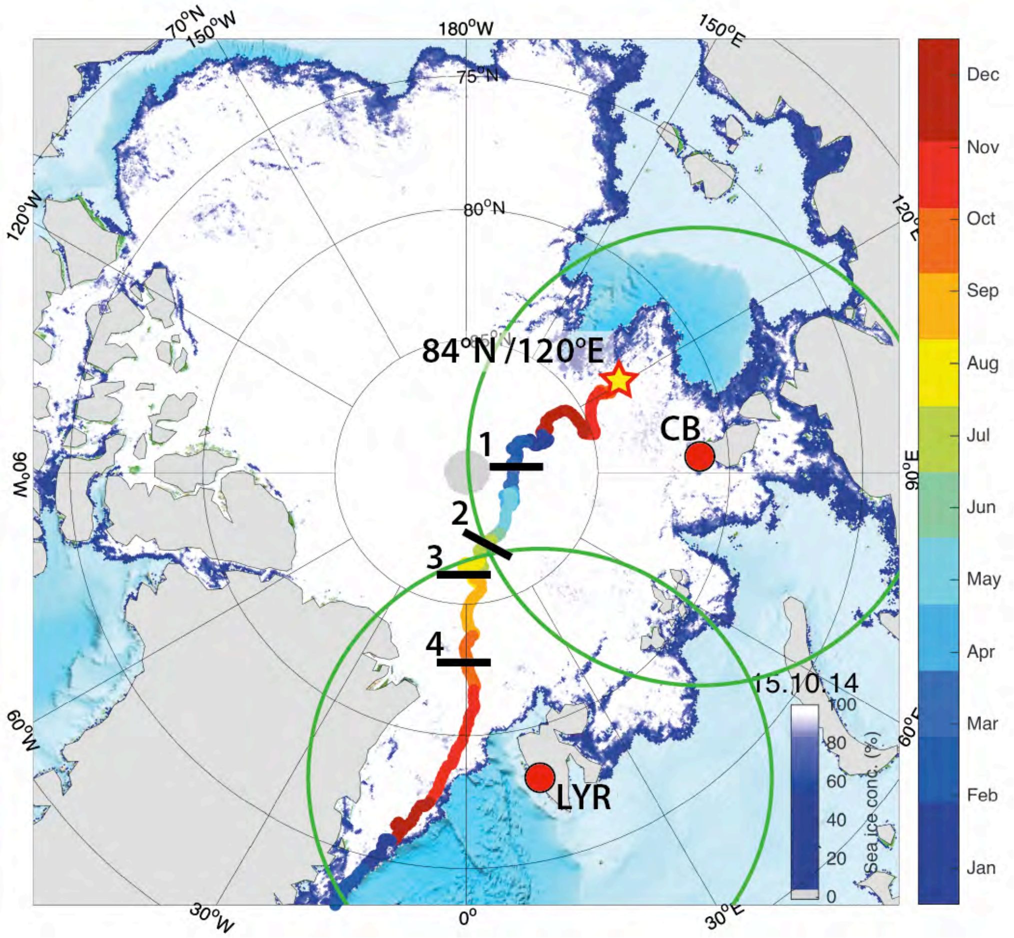

Fig. 4.2: Drift trajectories for the selected starting position at 120°E and 84°N. Colors represent the month of the drift. Green circles show helicopter ranges from Cape Baranov (CB) and Longyearbyen (LYR). Numbers and black ticks indicate where the resupply would happen based on this trajectory. (Simulations: T. Krumpen, Figure: M. Nicolaus)

Supply schedule and procedures / logistics

In addition to the general time line in Section 4.1, this section contains more details on the required logistics, in particular the procedures for resupply.

Mobilization in Tromsø (end 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 mid-September. In Tromsø an extended harbor time, e.g. 5 days, is required in order to prepare for MOSAiC. 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

TABLE 4.4: Primary logistics activities during the 6 legs. Projected fuel amounts assuming consumption of 35 tons/day while underway and 15 tons/day in passive drift.

Leg	Date	Action	Requirements	Fuel est. (tons)
1	01 Oct 19	Start of Leg 1 / leave TROMSØ		2400
	10 Oct 19	Arrive at Central Observatory floe position in Laptev Sea (e.g. 84°N/ 120°E) and identify suitable ice floe		
	11 Oct 19	Start to deploy distributed network	Russian ship e.g. Academic Federov	
	14 Oct 19	Refueling (400 tons) at start location Ship takes deployers home	Russian ship e.g. Academic Federov	2000>2400
	15 Oct 19	Drift starts		
	18 Oct 19	Time series start		
	12 Dec 19	Scientist exchange	Helicopter via Cape Baranov	
2	13 Dec 19	Start of Leg 2		
	13 Feb 20	Refueling Polarstern (1600 tons) Scientist and crew exchange	Russian nuclear icebreaker	555>2155
3	14 Feb 20	Start of Leg 3		
	09 Apr 20	Scientist exchange	Helicopter via LYR or Cape Baranov	
4	10 Apr 20	Start of Leg 4		
	11 Jun 20	Refueling Polarstern (1000 tons) Scientist and crew exchange	International icebreaker e.g. US Vessel or Swedish Oden	385>1385
5	12 Jun 20	Start of Leg 5		
	13 Aug 20	Refueling Polarstern (1000 tons) Scientist exchange	International icebreaker Snow Dragon possible	440>1440
6	14 Aug 20	Start of Leg 6		
	18 Oct 20	End of time series		
	21 Oct 20	End of drift Collect instrumentation from network Steaming to Bremerhaven	Evtl. support from other vessel	405
	31 Oct 20	Arrival Bremerhaven		55

Transit to the Drift Location (01-10 October 2019)

Polarstern will leave **Tromsø** on 01 October 2019 and head to 84°N, 120°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; Total transit of about 7 days. Thus, it is anticipated that a suitable location will be found before 10 October.

Installation of Distributed Network (10-15 October 2019).

Polarstern will work together with an escort ship (potentially AARI ship Akademik Fedorov or Treshnikov) to deploy the distributed network. Upon completion of Polarstern activities, the escort ship will transfer fuel (~400 tons) to Polarstern to top off its fuel bunker. Distributed network deployment crew will be transported back to mainland on the escort ship.

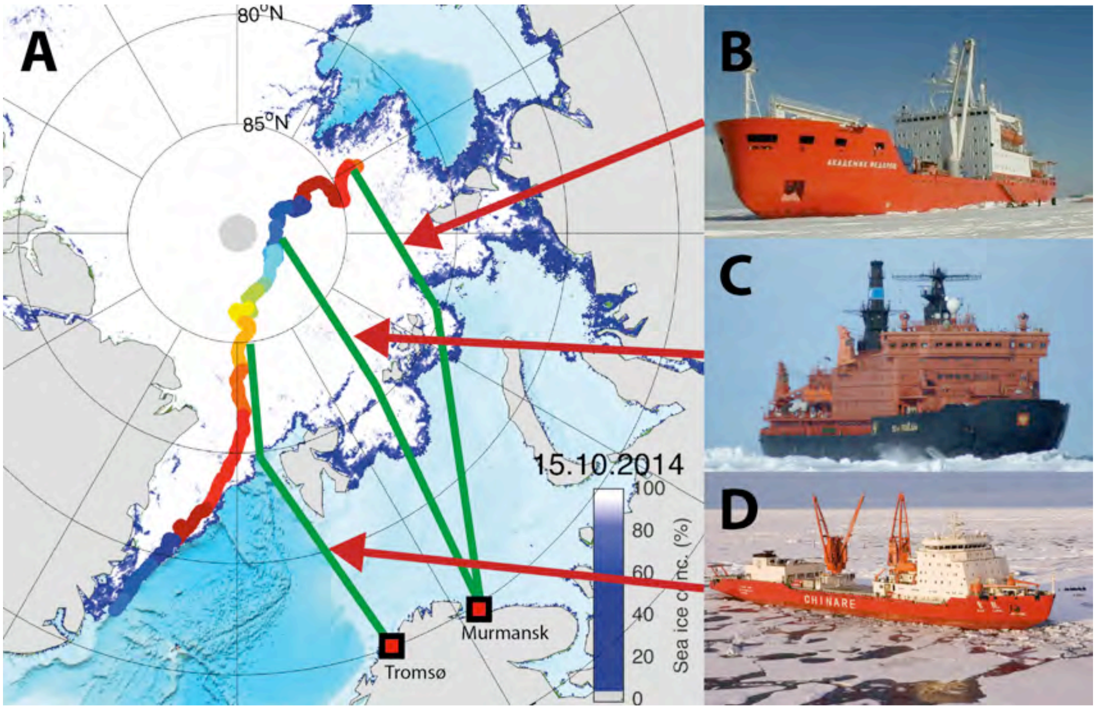

Fig. 4.3: The re-supply will be performed by different logistics and research vessels starting from Murmansk or Tromsø. (B) First resupply in October 2019, e.g. Akademik Fedorov or Treshnikov, (C) Second resupply in February by a nuclear ice breaker, (D) Third resupply in June by Xue Long. (Figure: M. Rex and M. Nicolaus)

Scientific Personnel Exchange (mid December 2019)

In December 2019, we will have the opportunity to exchange scientific personnel (up to 40 persons) via long-range helicopter from Cape Baranov, Russia. But there will likely be no opportunity for other resupply. The ship crew will not be exchanged at this time.

Refueling 2 (mid-February 2020)

The second refueling under hardest ice conditions will need the support of a Russian Nuclear icebreaker. 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.

Scientific Personnel Exchange (mid-April 2020)

In April 2020, we will have the opportunity to exchange scientific personnel via long-range helicopter or even by fixed-wing aircraft via Longyearbyen, Svalbard, or Cape Baranov, Russia. No additional exchange of crew or resupply is planned for this time.

Refueling 3 (mid-June 2020)

The third refueling in mid-summer is planned to be performed with the aid of the US or 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. We are currently aiming to get the Chinese Xue Long (Snow Dragon) vessel to provide additional 1000 tons of Arctic Diesel. This vessel could also help to exchange the scientist on board, and if needed also parts of the crew. In addition, food and equipment supply is possible.

End and Return to Port (October 2020)

The observational time series will end on about 18 October 2020. Assets on the ice camp adjacent to Polarstern will be packed. End of the drift will be on approximately 21 October. At that point Polarstern will start its voyage out of the ice and back towards Bremerhaven, with a target arrival date of 31 October 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 in close collaboration with the cruise leader.
- 2 Safety guards (see also Section 4.7)
- 1 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 berth 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)
- Setup and operation of the secondary ice camp (Section 3.5)
- 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 will be exchanged after each leg, while ship crew exchange will only happen during ship supply after every other 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 chief scientist, and the MOSAiC project coordinators. 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, lead for each observation team, 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, 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, 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, modifications to deployment, resupply 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 will be responsible for routine development of public relations materials including blog 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. 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

Scientific leadership for the MOSAiC observational phase will be provided by an interdisciplinary team of coordinators representing all observing teams and other programmatic priorities. The table below 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 4.5: Coordinators of the different Teams within MOSAiC with contact dates and Institution.

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@usace.army.mil	CRREL
	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
Data			
	Hannes Grobe	hannes.grobe@awi.de	AWI
Media			
	Ralf Röchert	Ralf.Roechert@awi.de	AWI
Remote Sensing			
	Ronald Kwok	ronald.kwok@jpl.nasa.gov	NASA, JPL
	Gunnar Spreen	gunnar.spreen@uni-bremen.de	UHB
Logistics			
	Uwe Nixdorf	uwe.nixdorf@awi.de	AWI
	Marius Hirsekorn	marius.hirsekorn@awi.de	AWI

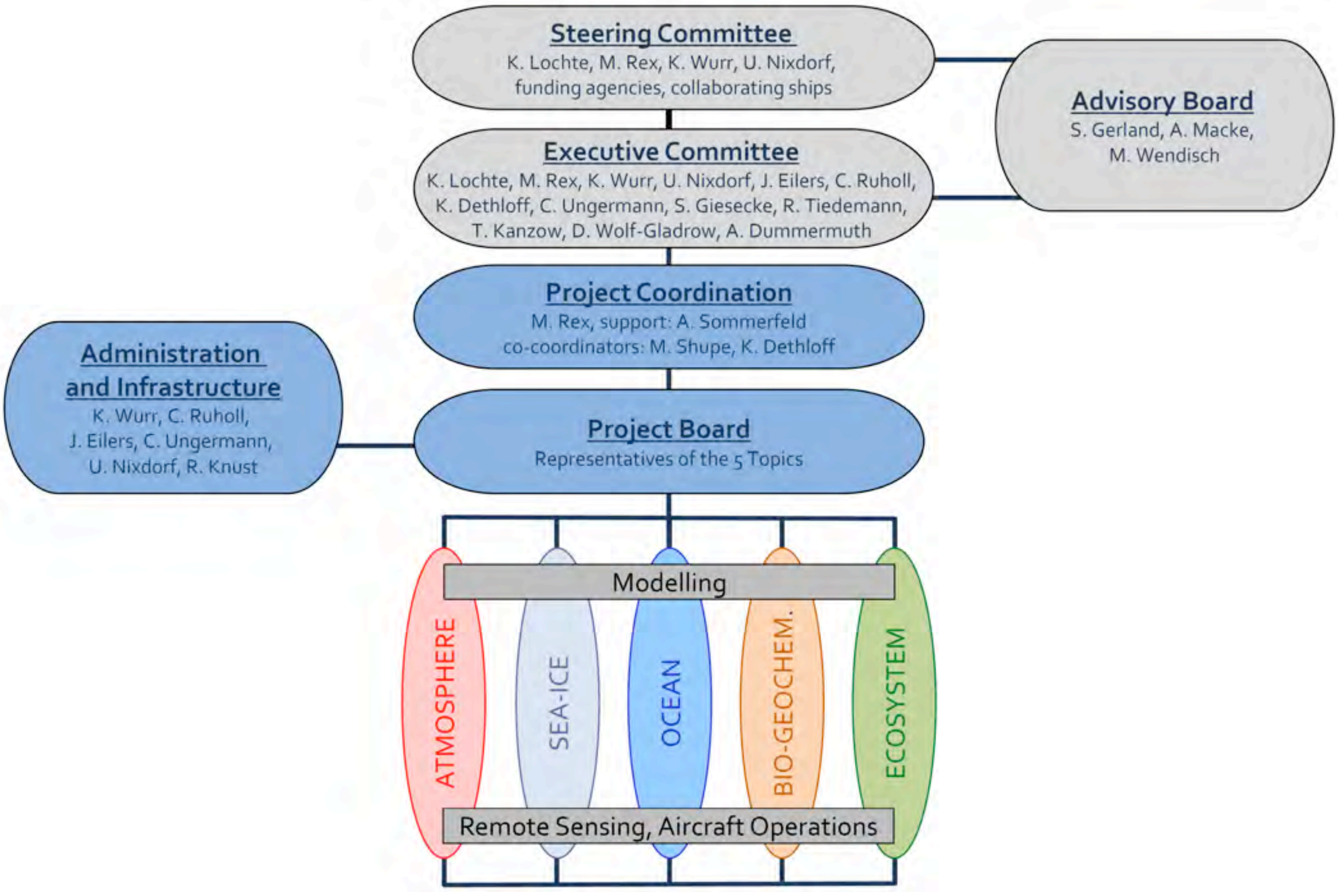

Fig. 4.4: Schematics of the organizational structure of MOSAiC, coordination within AWI and among all partners, including the teams described in Sections 4.1 to 4.5. (Figure: M. Rex)

Sub-teams and internal communication

During the preparation phase, we will establish additional teams, 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. The project lead and the team coordinators will establish different e-mail lists in order to organize all upcoming planning. In addition, the project homepage will host a sign-up sheet for e-mail lists. 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 4.1) 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 nuclear icebreaker. If a Russian nuclear icebreaker is not available there are two alternate plans envisaged:

- 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.

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 air planes and helicopters.

Impacts 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
- Exhaust (BC)
- Impacts ocean and atmosphere turbulence
- Light pollution
- Waste release (e.g. nutrients, tracers)
- Sea ice mechanics, local deformation and destruction of the ice floe (preconditioning of cracks)

Precautions

- 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, we 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, 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. 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 own 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.

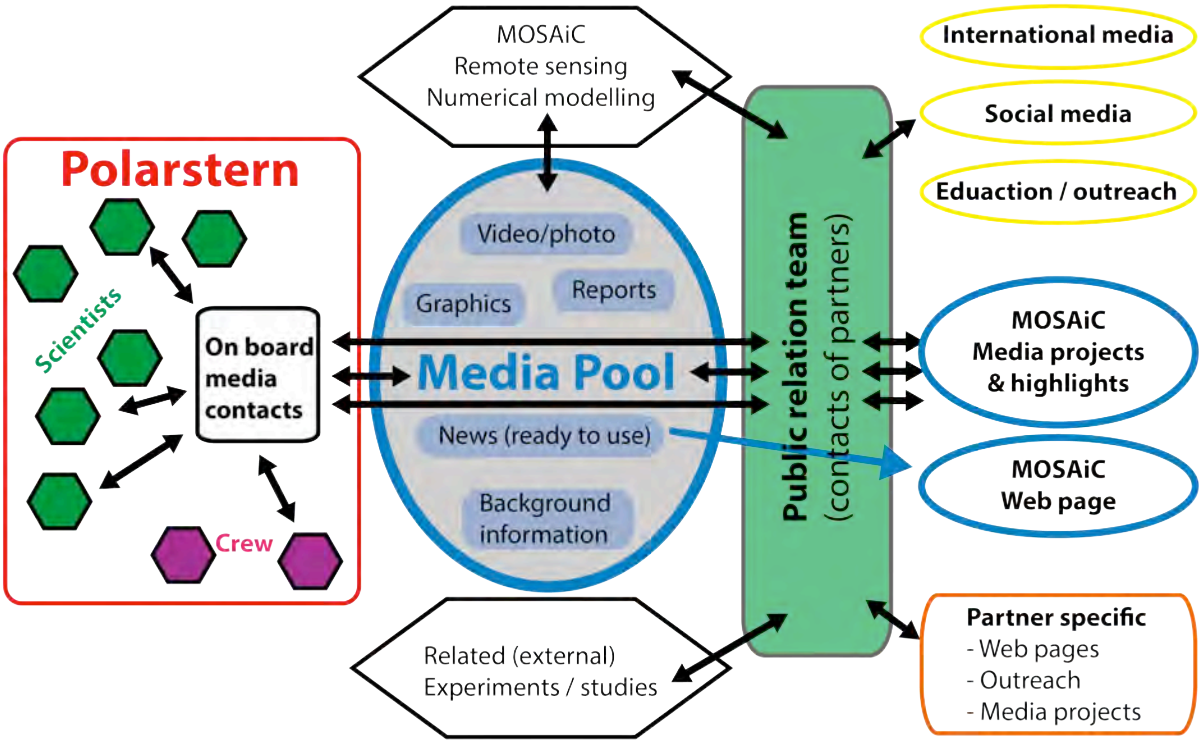

Fig. 4.5: Schematics of the media concept, including the role of the media contacts on board, the media pool, and the actors on the ice and back at home. (Figure: M. Nicolaus)

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 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, videos, photography, audio, interviews, 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

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

1. scientific satellite remote sensing
   - ground truthing of existing satellite data with in-situ observations
   - collect in-situ data to develop new or improve existing remote sensing methods need
   - 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
2. support of operations:
   - sea ice concentration
   - SAR imagery
   - weather data
   - high resolution visual images

5.1 Pre-drift Coordination of the Remote Sensing Program

Remote sensing team coordination

Need to establish a coordinated program for ordering / recording / archiving remote sensing data and keep track of available images / scenes, and their responsibilities. Things to coordinate in advance

- set up satellite team
- arrange responsibly for single satellites
  - data availability, incl. ordering
  - potential license issues, research permits
  - data reception and storage
  - data flow, eventually to Polarstern
- define needs for field measurements (see Section 5.2)
- develop data concept and contribute to data management plan (Section 7)

Linkage with in-situ data and post-drift data use

Most ground and satellite data will be available for the participating teams. Only in case of special agreements between single groups and space agencies, a free exchange of satellite data may be restricted. However, this is presumably not a problem since such data are ordered and used for focused studies carried out by single specialized groups.

5.2 Acquisition of Satellite Data during the Drift

Overview of satellites to be recorded

All based on current knowledge and plans, but it has to be considered, that changes and failures of single satellites may happen before or during the drift.

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

Satellite / Sensor	**For operation**	**Resolution / Swath width**	**Derived parameter**	**Partners**	**Comment**
SAR					
Sentinel 1	x		Sea ice type.		
Cosmo Skymed		100m	Sea ice type.	x	Only <81,25°N
TerraSAR-X	x	3m / 30km 40m / 260km	High res. images	x	X-band
ALSO-2			High res. images	x	L-band
Radarsat-2					
Altimeters					
CryoSat-2			Sea ice thickness		
Sentinel 3			Sea ice thickness		
IceSat-2			Sea ice thickness		
Radiometer					
SSMIS			Sea ice concentration		
AMSR-2			Sea ice concentration		
SMOS			Thin ice thickness		
SMAP			Sea ice brine		
Optical & infrared					
MODIS		0.25-1km/2.3km			
Sentinel-2					
Sentinel-3					
MetOP AVHRR3					
GOME-2			Ozone		
GOSAT			Greenhouse gases		
Scatterometer					
ASCAT				AWI	
Cloudsat			Clouds		

Transfer and on-board visualization of remote sensing information

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

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 pull-software 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 on board will visualize 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 itself is stored on a GeoServer and an archive accessible to all scientists on board.

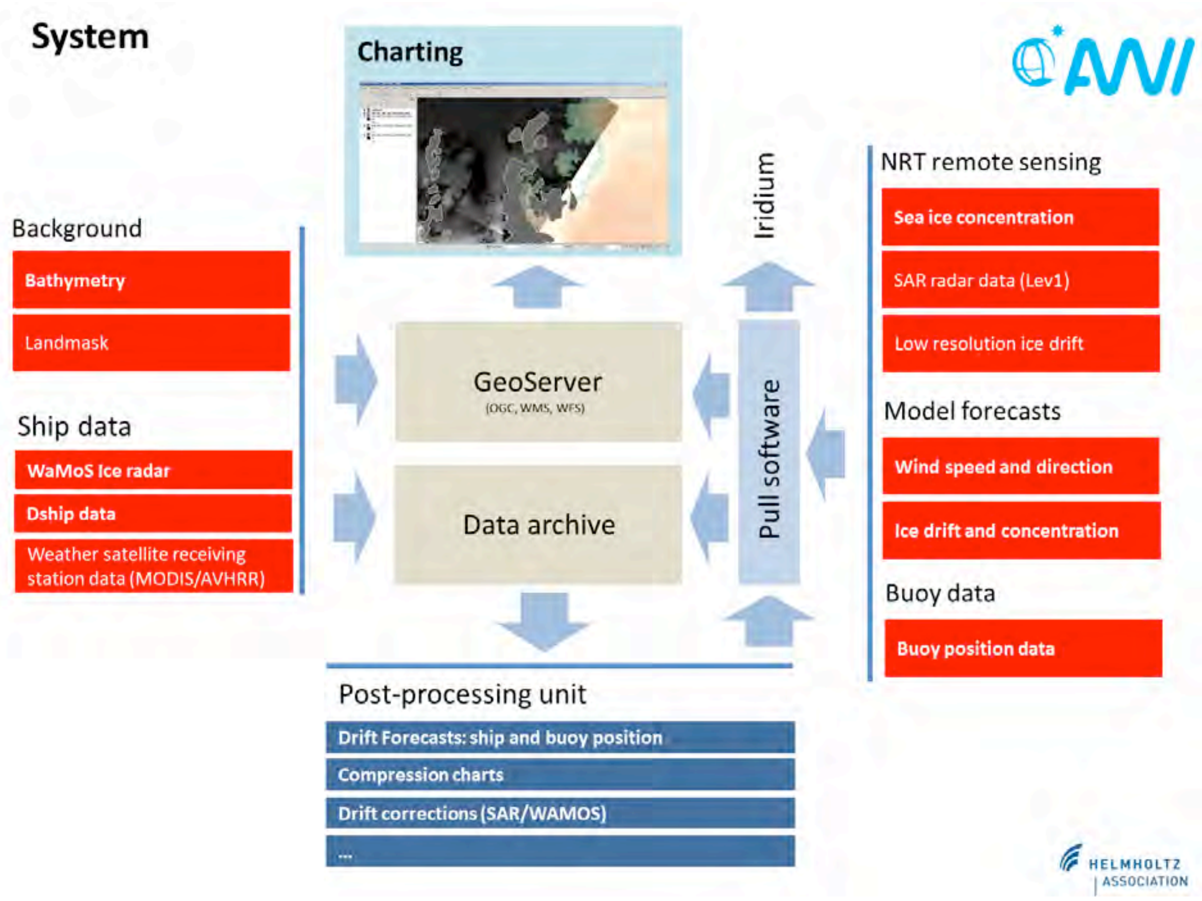

Fig. 5.1: System concept for transfer, storage and visualization of remote sensing and model data in combination with information from ship sensors and surrounding buoys to support decision making during MOSAIC.

Tasks on ship and support from home-based teams

Home-based coordination and ordering of satellite data acquisitions. This 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 in conjunction with special studies (e. g. SAR polarimetry, application of INSAR for retrieval of topography), dependent on the availability of suitable data (may have to be negotiated with space agencies); satellite data takes 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).

Satellite image receiving unit on Polarstern

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

5.3 Coordination with In-situ Measurements

Planning and implementation in the field in agreement with the teams on the ship, time for “warning in advance” has to be agreed upon

Important ground measurements

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

For all measurements, geographical coordinates are needed.

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)
- “Floe-hopping” with helicopter in an area covered by the respective satellite data takes and documentation of
    - 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)

6. IMPLEMENTATION OF NUMERICAL MODELS

Important element: forecast during the drift – drift forecast

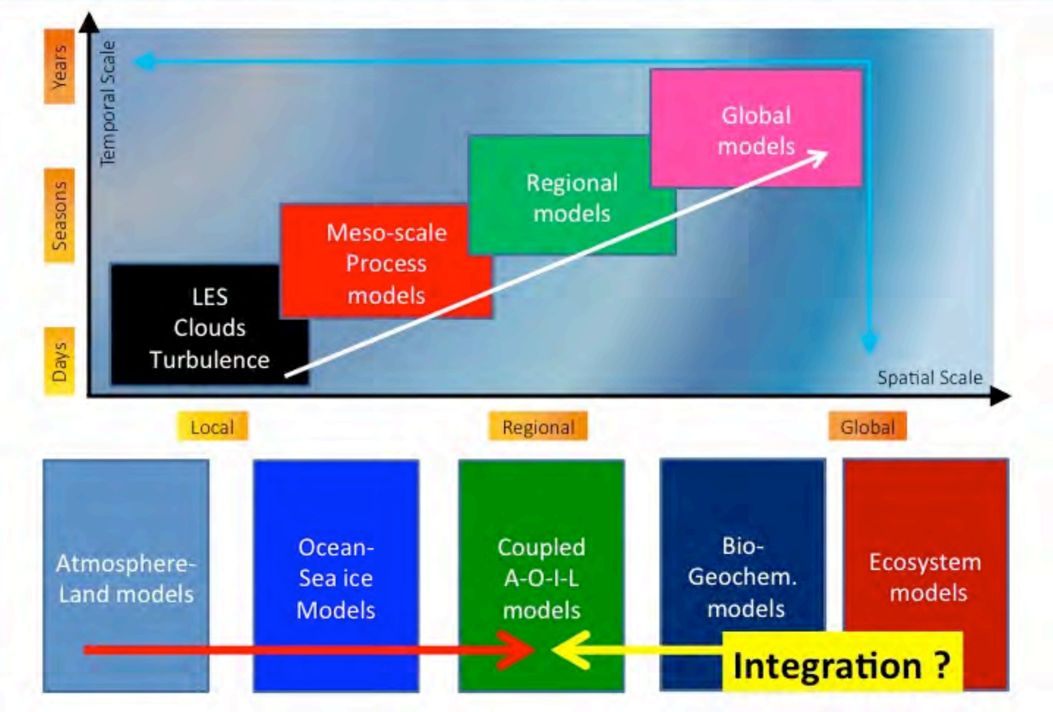

Fig. 6.1: Hierarchy of numerical models in MOSAiC. (Figure: K. Dethloff)

6.1 Operational Forecast of the MOSAiC Drift

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 forecast data.

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 forecast data provided by DWD.

Global forecasts

Operations during the MOSAiC drift might also benefit from current plans for a YOPP/MOSAiC Drift Forecast Experiment. If undertaken, this will be an international effort aiming at improved sea ice drift forecasting capabilities, motivated by MOSAiC. Conceptually similar to the "Sea Ice Outlook" initiative, several international groups would 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 could 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).

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 forecast data 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 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 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:

The 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 only 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 manifold, but poorly understood interactions between the surface, clouds, radiative and turbulent vertical fluxes in the ABL in the Arctic.

An advanced understanding of this 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 focusing mainly on the responses of lower trophic levels, primarily primary productivity on major physical and chemical drivers. Several models attempts exist that included sea ice biogeochemistry, mainly primary production models. Ice algal ecosystem model have successfully been coupled with the global physical and open-ocean pelagic ecosystem models. 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. respiratin, 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 e.g. primary productivity are hampered by the lack of physiological data and incomplete information on the seasonal variability of e.g. nutrient fields which are relevant and used in such efforts.

The recent model inter-comparison highlights the substantial challenges in implementing realistic ecosystem models focusing on the most basic biological variable primary production. They revealed substantial differences in the primary productivity output generated and models did not agree even in the fundamental question whether nutrients or light are limiting algal growth, questioning the predictive capabilities of the current status of Arctic ecosystem models.

There is the needs for improved cooperation and communication between field going ecologists and ecosystem modelers and specifically asked for time series data on several locations as major need to develop and test approaches to numerical modeling of specifically the sea ice ecosystem. Here the MOSAIC program does play a highly important role to provide such data for a wide range of modeling efforts, including 1D to 3D ecosystem modeling but also for areas where biological activity might affect gas exchange, or DMS production.

Implementation of this interaction is at its beginning. Ideally a joint group of modelers and observationalists will develop a list of variables and parameters that will be consistently determined during MOSAIC over a complete seasonal cycle and also directly used in models both for the MOSAIC region but also for the entire Arctic domain. These synergies still need to be developed and strengthened.

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 MANAGEMENT PLAT AND POLICY

7.1 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 2018 (Section 4.1). It will be based on the input from the Pangaea editors, the project data manager, 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. 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 (Year of Polar Prediction).

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. 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.

7.2 PANGEA

The data of MOSAiC will primarily be archived, published and distributed through the data library PANGAEA - Data Publisher for Earth and Environmental Science (http://www.pangaea.de). PANGAEA is a member of the World Data System (WDS), hosted by AWI. 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 time and space. 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 a technical quality control on consistency, validity and completeness, data are stored in a consistent format with 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 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).

Data will be described using the metadata format ISO 19115. It is distributed on the Internet through web services with various protocols, a.o. 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. Google, DataCite or WorldCat. Part of each dataset is a citation including a DOI (Digital Object Identifier) for persistent identification. Central table in Pangaea is a feature 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.

7.3 Project Data Management and Publication

Dedicated data curators will operate as members of the project, considering the proximity to the data producers. Under the supervision of the project data manager and the Pangaea editorial board, they will collect metadata from platforms timely after production. Data from the investigators will be handled in close cooperation with 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 of 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 Arctic (IASOA) network of land-based atmospheric observatories, and the Russia research programs on Cape Baranov 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.

How do we “decide” what we consider a direct contribution or link to MOSAiC and what not? May be, we should, similar to YOPP, define some criteria of what we consider as a related project. This is in particular important with respect to our data management plan: where does MOSAiC end?

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.

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

Atmosphere (see Section 2.1)

TABLE 9.1: Atmospheric variables measured during MOSAiC.

	Method	Ice camp & PS	Distr. Network	>20 km
Basic meteorology	AWS	continuously		
	AWS	continuously		
	AWS		continuously, with relocations	
Humidity	f(RH)	continuously		
Fluxes of heat, momentum	Meteo. tower	continuously, with relocations		
ABL parameters	Portable stations		continuously, with relocations	
	UAV		?	
Fluxes of CO2, CH4	Meteo. tower w. eddy	continuously, with relocations		
Radiation	M-AERI, PIR, PRP, PSP, SPN, …	continuously		
Meteo. profiles	Radiosondes	continuously		
	OCEAN NET	continuously		
	ARM suite	continuously		
Ozone profiles	O3 sondes	weekly		
Wind profiles	Doppler lidar	continuously		
	Radar	continuously		
	SODAR	continuously		
Aerosols, column	CIMEL sun ph.	continuously		
Aerosols, profiles	HSRL	continuously		
Column. H2O	MW	continuously		
Precipitation	Disdrometer	continuously		
Aerosols in situ	CPC, MA, PSAP, nephelom.	continuously		
CCN	CCN	continuously		
Aerosol chemistry	PILS	continuously		
Trace gases	Mass spectrometer	continuously		
Clouds	Cloud radar (Ka band)	continuously		
	Cloud radar W-band	continuously		

	Scanning cloud radar (Ka/X bands)	continuously		
Cloud properties	MPL, HSRL, Ceilometer	continuously		
Clouds	Sky imager	continuously		
Others:				
Meteo. profiles	Drop sondes			spring IOP
	Drop sondes			?
ABL properties	Airborne sensors			spring IOP
	UAVs			spring / summer ?
	Tethered balloon	?		
Turbulence parameters	Aircraft			spring IOP
Albedo / melt ponds	Helicopter sondes			polar days
Remote Sensing Products	Satellite sensors			continuously, at home

Sea ice and snow (see Section 2.2)

TABLE 9.1: Sea ice variables measured during MOSAiC.

	Method	**Ice camp & PS**	**Distr. Network**	**>20 km**
Sea Ice				
Thickness	Survey lines	weekly		
	Drillings	weekly		
	Buoys	continuously	continuously	continuously
	Survey flights (EM)		weekly (weather)	weekly (weather)
	ROV, AUV	weekly		
Mass balance	Stakes & wires	weekly	continuously	continuously
	LIDAR & ROV	weekly		
Bottom topography	ROV & EM	weekly		
Freeboard	Leveling	monthly		
	High prec. Pressure sensors	continuously		
Density	Coring	monthly		
Salinity	Coring	monthly		
	Ice harp	continuously		
O18	Coring	monthly		
Texture	Coring	monthly		
Porosity (ice & ridges)	ROV+EM	weekly		
Stress	Stress buoy	continuously	continuously	

	High prec. GPS	continuously		
Strength	Borehole jack	opportunistically		
Floe size (distribution)	Survey flights (cameras)		weekly	weekly
Lateral melt / floe size	Survey flights (cameras)	days, seasonal	weekly	weekly
Core sample processing	Freezer Lab	weekly		
Snow				
Thickness	Survey lines	weekly		
	Buoys	continuously	continuously	continuously
	Survey flights (radar)		weekly (weather)	weekly (weather)
dg, rho, strati, hard, liquid w., ssa	Pits	weekly (melt+)		
Snow water equivalent	Samples	events		
Redistribution	Stations	continuously	continuously	continuously
	LIDAR	events		
Salinity, O18	Samples	events		
Temperature	Pits	weekly (melt+)		
	Thermistor strings	continuously	continuously	continuously
Surface roughness	LIDAR	events	events	events
Surface properties	Cameras	continuously	continuously	continuously
Melt ponds				
Depth	Surveys	probes, daily	days	
	Lidar / Stereocam		days	
Geometry	Cam flights	continuously	days	
Coverage	Cam flights	continuously	days	
T,S	Profiles	days		
False bottom	ROV multibeam	days		
Optics				
Irradiance, spectral	Station / buoys	continuously	continuously	continuously
Albedo, spectral	Station / buoys	continuously	continuously	continuously
	Transects	weekly to daily		
Transmittance, spectral	Station / buoys	continuously	continuously	continuously
	Transects	weekly to daily		
	ROV	weekly to daily		
IOP, spectral	Station / buoys	continuously		
	Profiling	days to daily		
Impurities	Samples	samples		
Top 5 m ocean				
T, S	On-ice CTD	continuously		
	ROV	days		
Heat fluxes	Turbulence	continuously		

	installation			
Others				
MW properties (L & Ku)	Scatterometer	weekly	weekly (weather)	weekly (weather)
	Station	continuously		
Location	GNSS / GPS	continuously	continuously	continuously
Deformation	Ship Radar	continuously		
	Airborne images	weekly	weekly (weather)	weekly (weather)
Visible images	Cams, time laps	continuously	continuously	continuously
	Airborne images	weekly	weekly (weather)	weekly (weather)
IR images	Cams, time laps	continuously		
Ice conditions	Bridge observations	daily		

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)	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily of more frequent	
Nitrate	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
Chl a fluorescence	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
CDOM/FDOM	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
Dissolved oxygen	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
Nitrate	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
pH	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
PAR	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
T microstructure (turbulence)	ITP / IAOOS, under-ice chains, in-/under-ice systems	(potentially daily or more frequent, could replace manual	daily or more frequent	

		daily profile)		
Velocity	ITP / IAOOS, AOFB, other under ice ADCP	(potentially daily or more frequent, could replace manual daily profile)	daily or more frequent	
Mobile vehicle surveys				
T/S	Glider (AUV, ROV)		continuously (events)	events
Chl a fluorescence	Glider (AUV, ROV)		continuously (events)	events
Dissolved oxygen	Glider (AUV, ROV)		continuously (events)	events
T microstructure (turbulence)	Glider (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.	days	events	events
CH4	Ice cores, chamber measurements	days	events	events
CO	Ice cores, chamber measurements	days	events	events
VOC	Ice cores	days	events	events
Sulphure cycle				
DMS, DMSP, DMSO	Ice cores, snow	days	events	events
		days	events	events
Nitrogen cycle				
N2O, NOx	Ice cores, snow	days	events	events
Halogens	Snow, ice cores	daily (winter, spring IOP)	events	events
Mercury	Snow, ice cores	days	events	events
Natural radionuclides	Snow, ice cores	days	events	events
Lower troposphere				
Ozone	Air-measurements	daily (winter, spring IOP)	events	events
Halogens	Air-measurements	daily (winter,	events	events

		spring IOP)		
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**
General sea ice coring	Ice coring	days	opportunistically	seasonal / events
Water column nutrients	Under ice & depth profiles down to bottom, underway sampling	continuously	opportunistically	seasonal / events
Core bulk variables (Chl a, POC, PON, BSi, pigments)	Ice core & water sampling	days	opportunistically	seasonal / events
Seawater carbonate chemistry (TA, DIC)	water depth profiles	days	opportunistically	seasonal / events
Primary production	Ice core & water depth profiles euphotic zone	days	opportunistically	seasonal /events
Primary production	Under ice	days	opportunistically	seasonal / events
Primary production	Online sampling	continuously	opportunistically	seasonal / events
Autotrophs; abundance, classic species distribution	Ice core & water sampling	days	opportunistically	seasonal / events
Autotrophs; abundance, species distribution	Under ice sampling	days	opportunistically	seasonal / events
Bacteria production	Ice core & water depth profiles down to bottom	days	opportunistically	seasonal / events
Organic matter cycling, DOC, DOM, Gels, TEP	Ice core & water depth profiles down to bottom	days	opportunistically	seasonal / events
Meiofauna / Microzooplankton	Ice core & water depth profiles euphotic zone	days	opportunistically	seasonal / events
Zooplankton / polar cod	Water column	days	opportunistically	seasonal / events

Zooplankton / polar cod	Under ice sampling	days	opportunistically	seasonal / events
Molecular approach: protists + prokaryotes , DNA, RNA for algae, bacteria, archaea	Ice core & water sampling	days	opportunistically	seasonal / events
Nitrogen cycle: NO3,NO2, NH4, DON, PON, N2 - isotopes, conc and fluxes	Ice core & water sampling	days	opportunistically	seasonal / events
Nitrogen cycle	Water column	days	opportunistically	seasonal / events
Export fluxes, long-term-traps	Under ice sampling	days	opportunistically	seasonal / events
Export fluxes, short-term-traps	Under ice sampling	days	opportunistically	seasonal / events
Export fluxes, UVP, particles analysis	Water column	days	opportunistically	seasonal / events
Export fluxes, 234Th	Under ice water & water depth profiles down to bottom	days	opportunistically	seasonal / events
Gliders (O2, CDOM fluorescence, microstructure (T,S)	Under ice deployment of autonomous devise	days	opportunistically	seasonal / events
Productivity - Ar/O2 ; 14C-uptake, FRRF	In situ	days	opportunistically	seasonal / events

9.2 Preliminary Table of Partners

The following institutes/partners are currently involved in MOSAiC. This list is not complete jet 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	
ECMWF	European Centre for Medium-Range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
IASC	International Arctic Science Committee
Belgium	
ULB	Université Libre de Bruxelles
UOL	University of Liège
Canada	
UOM	University of Manitoba
York	York University

China	
Shanghai	Chinese Polar Research Institute
Denmark	
DMI	Danish Meteorological Institute
Finland	
FMI	Finish Meteorological Institute
France	
LATMOS/UPMC	Laboratoire Atmosphères, Milieux, Observations Spatiales at University Pierre und Marie Curie
LOCEAN/UPMC	Laboratoire d'Océanographie et du Climat at University Pierre und Marie Curie
LSGE	Laboratoire de Glaciologie et Géophysique de l'Environnement
MIO	Mediterranean Institute of Oceanography
Germany	
AWI	Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research
DWD	Deutscher Wetter Dienst (German weather service)
UHB	University Bremen
UHH	University of Hamburg
UTR	University of Trier
TROPOS	Leibniz Institute for Tropospheric Research
TUB	Technische Universität Braunschweig
Great Britain	
BAS	British Antarctic Survey
UEA	University of East Anglia
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
Netherlands	
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
USA	
ARM	Atmospheric Radiation Measurement Facility
CIRES	Cooperative Institute for Research in Environmental Sciences
CRREL	Cold Regions Research and Engineering Laboratory
CU	Colorado University
DOE	Department of Energy
FIU	Florida Institutional University
JPL	Jet Propulsion Laboratory
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NPS	Naval Postgraduate School

NSIDC	National Snow and Ice Data Center
OSU	Oregon State 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
Shirshov	Shirshov Institute Moscow
Switzerland	
EPFL	École Polytechnique Fédérale de Lausanne

9.3 Lists of Abbreviations / Acronyms

Methods / Instruments

TABLE 9.7: Abbreviations for methods and instruments.

ADCP	Acoustic Doppler Current Profilers
AOFB	Arctic Ocean Flux Buoy
AUV	Autonomous Underwater Vehicle
GOSAT	Greenhouse gases observing satellite
HEM	Helicopter Electro Magnetics
HIRHAM	High Resolution Hamburg Model
IMB	Ice Mass Balance Buoy
ITBOB	Ice-tethered Bio Optical Buoy
ITM	Ice-tethered Microprofiler
ITP	Ice-tethered Profiler
LOKI	video-optical casts
Lab	Laboratory
MetOp	Meteorological Operational Satellite
NAOSIM	North Atlantic Arctic Ocean Sea Ice Model
NAVB	Navigation Buoy
NWP	Numeric weather prediction
RCM	Regional climate model
ROV	Remotely Operated Vehicle
RV	Research vessel
SEBS	Surface Energy Budget Station
SMAP	Soil Moisture Active Passive
UAV	Unmanned Aerial Vehicle
UTB	Up-Temp-O Buoy
WRF	Weather Research and Forecasting Model

Projects / Programs

TABLE 9.8: Abbreviations for Projects and Programs.

AMAP	Arctic Monitoring and Assessment Programme
ArCS	Japanese Arctic Challenge for Sustainability
ARM	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
EPP	Environmental Prediction Plan
ESSD	Earth System Science Data
IAOOS	Ice-Atmosphere-Arctic Ocean Observing System
	International Arctic System for Observing the Arctic
ICARP III	Third International Conference on Arctic Research Planning
ISDAC	Indirect and Semi-Direct Aerosol Campaign
MPACE	Mixed-Phase Arctic Cloud Experiment
SHEBA	Surface Heat Budget of the Arctic Ocean
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
BSi	Biogenic Silica
C	Carbon
CDOM	Colored dissolved organic matter
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
N2O	Nitrous oxide
NOx	Nitrogen oxide
O/O2	Oxygen
POC	Particular Organic Compounds

PON	Particular Organic Nitrate
S	Salinity
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
NRT	near real time
PDF	Probability density function
IOP	Intensified Observation Period
LES	Large-Scale Eddy Simulations
LYR	Longyearbyen
SCM	Single column model
U	University

The Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) is a key international flagship initiative under the auspices of the International Arctic Science Committee (IASC). The main aim of MOSAiC is to improve our understanding of the functioning of the Arctic coupled system with a complex interplay between processes in the atmosphere, ocean, sea ice, and ecosystem coupled through biogeochemical interactions. The main objective of MOSAiC is to develop a better understanding of these important coupled-system processes so they can be more accurately represented in regional- and global-scale weather- and climate models. Observations covering a full annual cycle over the Arctic Ocean of many critical parameters such as cloud properties, surface energy fluxes, atmospheric aerosols, small-scale sea-ice and oceanic processes, biological feedbacks with the sea-ice ice and ocean, and others have never been made in the central Arctic in all seasons, and certainly not in a coupled system fashion. The main scientific goals focus on data assimilation for numerical weather prediction models, improved sea ice forecasts and climate models, ground truth for satellite remote sensing, energy budget and fluxes through interfaces, sources, sinks and cycles of chemical species, boundary layer processes, habitat conditions and primary productivity and stakeholder services. In view of these important expected outcomes and the international collaborative character of MOSAiC IASC endorses this initiative with great enthusiasm.

Susan Barr, IASC President