6. ECOSYSTEM SCIENCE

Allison Fong[1], Robert Rember[3], Nicole Hildebrandt[1], Jian Ren[4], Pauline Snoeijs-Leijonmalm[5], Anders Svensson[6], Musheng Lan[7], Jessie Creamean[8], Sebastian Rokitta[1]

(not on board:) Rolf Gradinger[2], Sinhue Torres-Valdes[1], Julia Grosse[9], Anja Engel[9], Mats Granskog[10], Philipp Assmy[10], Lasse Olsen[16], Guilia Castellani[1], S. Lena Eggers[1], R. Campbell[11], Laura Wischnewski[1], Clara Hoppe[1], Björn Rost[1], Boris Koch[1], Susanne Spahic[1], F. Schaafsma[12], Anders Torstensson[13], Stefan Bertilsson[13], Carin Ashjian[14], Adam Ulfsbo[15], Agneta Fransson[10], Ana Aguilar-Islas[3], Eva-Maria Nöthig[1], Hauke Flores[1], Daniel Scholz[1], Y. Zhuang[4], Martin Graeve[1], Celia Gelfmann[11], Oliver Müller[16], Gunnar Bratbak[16], Aud Larsen[16], Barbara Niehoff[1], Emelia Chamberlain[17], John-Paul Balmonte[13], Kai-Uwe Ludwichowski[1], Phil Alatalo[14], Katja Metfies[1], Katrin Schmidt[18], Angus Atkinson[18], Elise Droste[19], Dorothee Bakker[19], Charlotte Havermans[1], Eva Leu[19], Melissa Chierici[20]

[1]DE.AWI
[2]NO.UIT
[3]EDU.UAF
[4]CN.SIO
[5]SE.SU
[6]SE.SLU
[7]CN.PRIC
[8]EDU.CSU
[9]DE.GEOMAR
[10]NO.NPOLAR
[11]EDU.URI
[12]NL.WUR
[13]SE.UU
[14]EDU.WHOI
[15]SE.GU
[16]NO.UIB
[17]EDU.UCSD (SIO)
[18]UK.AC.Plymouth
[19]NO.Akvaplan Niva
[20]NO.IMR

Grant-No. AWI_PS122_00

A comprehensive summary of the ecosystem measurements during all 5 cruise legs will be published in the *Special Feature: The Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC)* of the scientific journal *Elementa: Science of the Anthropocene* (https://online.ucpress.edu/elementa/collection/269/Special-Feature-The-Multidisciplinary-Drifting)

Background

High-latitude ecosystems, which use sea ice as a substrate, habitat, and foraging ground, are characterized by strong spatial heterogeneity and pronounced seasonal dynamics relative to their physico-chemical environment. The coupled interactions between sea ice, biology, and chemistry of the ocean-atmosphere system are, however, generally understudied. As a consequence, biological and ecological impacts on the Arctic climate coupled system are not well represented in regional and global climate models of the Arctic climate system. However, biological activities drive transformations of organic matter and elements, and can control the cycling of climate-active gases (i.e. CO_2, CH_4, N_2O, and dimethyl sulfide [DMS]) across atmosphere-ice-ocean interfaces. Therefore, biological activities mediated by microbes and small animals are important feedback mechanisms in the processing of key elements and gases in the Arctic climate. With MOSAiC, a more complete accounting of inventories and fluxes of essential elements and compounds (C, N, O, P, S) between the atmosphere, ice, and ocean systems will be gained through a broad appraisal of ecosystem properties and processes across sea ice and the underlying ocean.

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

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

Biological and biogeochemical processes are spatially heterogeneous due to patchiness in ice structure, microbial communities, and biophysical interactions within the ocean. Moreover, both the magnitude and direction of biogeochemical fluxes appear to evolve with season and with the advance of ice age. Multiple, spatially distributed measurements will be made within the local domain (<2 km) throughout the annual cycle to characterize the biology and biogeochemistry of the ice-dominated CAO ecosystem.

Objectives

MOSAiC Ecosystem objectives are:

1. Quantify components of the inorganic and organic carbon system, primarily in sea ice and the underlying ocean. Produce an annual mass budget of organic and inorganic carbon and alkalinity from FYI and SYI. These measurements will address recent and longstanding questions related to the net air-ice flux of CO_2 in addition to the potential for organic carbon trapping and dark period respiration to CO_2.
2. Produce an annual mass balance of the cycling of macro and micronutrients across the sea ice-water interface Characterize vertical fluxes of nutrients in combination with nutrient tracer assays to understand carbon and nitrogen recycling pathways by microbes in sea ice and seawater. We aim to measure the progressive concentration of nutrients, including iron, in sea ice over the ice formation season.
3. Establish several semi-autonomous measurement nodes on the main floe to measure oxygen and nitrate concentrations, and optical properties in the upper ocean. Together these measurements could establish whether the sea ice zone is a net producer of O_2 (net autotrophy) or a net producer of CO_2 (net heterotrophy). Sensor packages enable more highly time-resolved fluctuations in the proportion of O_2 versus CO_2 production from sea ice and the upper ocean over the annual cycle than can be captured by discrete sample collections.
4. Quantify primary and bacterial production in sea ice and the upper ocean. Compare estimates of net community production and net primary production from O_2/Ar ratios and ^{14}C-tracer assays to relate rates of organic matter fluxes to inventories of carbon and nutrients.

5. Assess particle fluxes including optical imaging instruments, including a LISST, UVP, and LOKI. Deploy a variety of sediment trap arrays to address different temporal scales of particle flux over the annual cycle. Couple particle flux estimates derived from imaging tools to discrete measurements of material fluxes generated from suspended POM and sediment trap collections of sinking POM to identify processes, which result in high flux events.
6. Measure the cycling of DOC and DOM, and characterize the composition of DOM derived from sea ice and the upper ocean. Assess which biological activities influence changes in the distribution and quality of DOC and POC.
7. Measure the temporal evolution of organismal distributions in sea ice and the ocean. Measure the spatial distribution of sympagic and planktonic biomass (e.g., ice algae, phytoplankton, microbes, micro- and meso-zooplankton) and determine their biodiversity.
8. Quantify biological rate processes that determine the inventories of elements and compounds across different trophic levels. Organic matter remineralization, microbial respiration, micro-zooplankton feeding and growth, and meso-zooplankton feeding, respiration, growth, and reproduction will be measured.
9. Determine standing stocks and distributions of microorganisms and animals to evaluate the physical-biological interactions that impact production, pelagic retention and vertical export below the halocline.
10. Evaluate impact of behavioral (e.g. vertical depth preferences and diel or ontogenic vertical migration) and life history (e.g. reproductive timing and overwintering strategies) patterns on nutrient fluxes, organismal abundance, and biomass in the ecosystem.

Work at sea

Ship-based and on-floe observations and activities were conducted to support core objectives and provide essential information to project-specific goals. Ecological properties were mainly derived from discrete physical sampling of the Arctic environment (air, snow, ice, and water). We also supplemented discrete measurements with [semi]-autonomous measurement packages, which provide higher temporal resolution of key properties from distinct positions on the primary ice floe. A small number of sensor packages and hydrographic buoy systems were deployed thru the ice to provide basic chemical and physical data at the atmosphere-ice-water interface. Ecosystem discrete sampling of snow, ice, and seawater occurred within 1 - 2km of the *Polarstern*.

During leg 1, we established a time-series of ecological, biogeochemical, and biological properties and processes using a coordinated effort across teams to capture a suite of properties once per week from all components of the Arctic climate system. For nearly 7 weeks, we conducted cooperative sampling with teams ICE and OCEAN to measure changes in biological components with respect to the physical and geochemical properties of snow, ice, and seawater. Core variables coordinated by Team ECO were primarily collected from the CTD-rosette water sampler deployed from *Polarstern* thru an ice hole alongside the ship. Additionally, we established two large ice coring sites, approximately 1.2 km from *Polarstern,* to support repeat visits and coring activities of the year-long campaign. While there are finer delineations of types of MYI and FYI within the CAO, the primary time-series was designed to track major property differences between newly formed ice originating in autumn 2019 (FYI) against ice that had survived summer melt (SYI). Common coring activities and approaches are further described in Section 8.2.

Other activities include the operation of an underway membrane inlet mass spectrometer (MIMS), deployment of visual camera systems, installation of a biogeochemical sensor package, deployment of an ice-tethered sediment traps, and deployment of an assortment of underwater nets for small animal capture. Camera systems are pre-programmed and deployed for months-long durations. A HD video camera system was deployed Met City at 375 m depth within the Central Observatory to monitor the presence of macrofauna in the mesopelagic. More detailed information is provided in section 6.7.

Under-ice ROV net sampling and video recording. Visual inspections of under-ice topography and associated flora and fauna will be possible using the ROV. We collected discrete samples of animals and flora from the ROV, which will be complemented by its suite of sensor measurements (i.e. light spectra, fluorescence, etc.). A summary of the ROV net casts is described in section 6.2.

The MIMS was operated in continuous measurement mode throughout the duration of leg 1. It is connected to the underway seawater intake system, which provides a continuous flow of fresh seawater from ~ 11 m depth. The MIMS measures concentrations of dissolved oxygen and argon in seawater, and the ratio of the two is used to determine the recent biological activity in surface seawater. Oxygen is produced and utilized by organisms, while argon is not involved in biological activities. Therefore, when measured in high temporal resolution, the ratio of O2/Ar, and relative changes in this ratio can be used to determine changes in biological activity. The MIMS was calibrated daily with reference gases of pure nitrogen (no oxygen, no argon) and an artificial mixture of air (21% nitrogen, 1% argon).

A large McLane sediment trap was deployed at the SYI dark site at the beginning of the scientific campaign by the SIO group. The sediment trap is suspended at 200 m depth and programmed to collect sinking material at 2-4 week intervals over the course of the whole year. Detailed descriptions of the sediment trap array can be found in section 6.6.

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

Water column discrete sampling

MOSAiC Ecosystem team coordinated properties were primarily collected from CTD-rosette casts and net tows conducted from the *Polarstern*. For CTD-rosette water sampler casts and information about the specific properties and quantities collected, refer to device operation IDs for CTD_SBE9plus_321, and subdirectory folders in the MCS under CTD_SBE9plus_321/exdata. A summary of the Ecosystem coordinated core variables are summarized in Table 6.1.1 Ecosystem project-specific rate measurements are summarized in Table 6.1.2. Additional project-specific variables collected during leg 1 are detailed in the following sub-sections. The sampling of water column ecological properties in MOSAiC follows protocols of international hydrographic programs, which routinely sample geochemical and biological properties. The once per week sampling of the full complement of water column properties is a joint effort between teams OCEAN, BGC, and ECO, thereby ensuring temporally co-located measurements of the ocean.

In brief, discrete water column sampling from *Polarstern* on leg 1 occurred routinely from Thursday to Saturday. We conducted 5 weeks of measurements using large gear deployed from *Polarstern*. Please refer to the device operations IDs in Appendix x.x. for more specific information. During the 3-day water column sampling period, we had a total of 11.5 hours of wire time on Thursday, 7.5 hours of wire time on Friday, and 6 hours of wire time on Saturday. Reduced wire time over a greater number of days than previously planned resulted in reductions of throughput for certain parameters and/or measurements. At the time of writing, Saturday sampling did not consume the full 6 hours of allotted wire time. Wire time will be utilized as more project-specific work comes online throughout the campaign, including on Leg 2. Therefore, the wire time allotted is required to support the planned activities within the Ecosystem work package.

A summary of the total number of unique samples and volume of seawater processed per cast during leg 1 is summarized in Table 6.1.3. This summary includes volumes and samples processed for both core variables and project-specific work.

While more than 80% of Ecosystem core variables were collected from the water column, there are several outstanding variable and processes that we were unable to collect and/or process from CTD casts. Primary production and bacterial production measurements were not conducted during leg 1. The limitation was time of specific personnel to conduct the assays in the radioisotope container. The second limitation was recurring issues with temperature control within the radioisotope lab container (i.e. too warm). Primary and bacterial production measurements were not limited by the water budget of the full depth cast. Additionally, DOM solid phase extraction (SPE) procedures were not possible during leg 1. The laboratory setup did not have all the necessary components to execute the assay, and we did not possess the personnel time for processing. Setting up and running of the AUTO-FIM was also not possible during leg 1. Onboard analysis of chlorophyll a and flow cytometry samples was also planned, but not possible to execute during leg 1. We did not possess the personnel time and expertise capacity to execute these onboard analyses within the weekly routine. Efforts to conduct these measurements on leg 2 will be prioritized.

Tab.6.1.1: Ecosystem coordinated core variables.

Ecosystem Core Variables	**Environments & Resolution**	**Method**	**Location: *Polarstern* and coring sites**	**Leg 1 Summary**
Macronutrients (nitrate, nitrite, ammonium, phosphate, silicic acid, DON, DOP)	Water: 10 – 20 depth horizons Sea ice: every 5 cm	SEAL AA3 Auto-analyzer Onboard *Polarstern* TN/TP (frozen, onshore only)	1x per week; additional shallow casts when time allows	Primarily collected from full water column depth casts on Thursdays (12-20 horizons per sampling event; from 4400 m to surface)
Dissolved Oxygen (DO)	*Water: 6 – 10 depth horizons* *Sea ice: none (sensor-based)*	*Winkler titration*	*1x per week*	*Not collected because onboard Winkler titration system does not work*

Carbonate chemistry (TA, DIC)	Water: 10 -16 depth horizons Sea ice: every 10 cm	Coulometry & VINDTA	1x per week	Primarily collected from full water column depth casts on Thursdays (10-16 horizons per sampling event; from 4400 m to surface)
DOC/DOM concentration and characterization; CDOM	Water: 6 - 10 depth horizons Sea ice: 0-5, 5-10, then every 10 cm	Solid phase extraction (onboard) FT-ICR-MS	1x per week	GF/F pre-filtered DOC samples collected from full depth cast; 0.2 micron PES pre-filtered DOC samples collected from FYI and SYI samples; DOM SPE not conducted
Oceanic particle size spectra and distributions;	Water column only; Sensor mounted on CTD-rosette package	Optical - Underwater Vision Profiler (UVP): *Polarstern* rosette only	1x per week	Activated on all CTD casts; multiple profiles per week from Thursday to Saturday
Sinking Particulate carbon, nitrogen phosphorus, and biogenic silica (POC, PON, POP, BSi)	Single Depth horizon for HydroBios 6-cup trap, deployment duration 4-8 weeks; PIT traps, depth horizons tbd, Deployment time 1-3 days	In situ traps C/N elemental analyzer Spectrophotometry Wet-alkaline method	HydroBios – 1x month PITs – 1x month leg 1; 0x leg 2, 2x month leg 3, 1x per week legs 4-6	HydroBios Trap not deployed; PIT traps not deployed; McLane trap deployed by SIO group (refer to section 6.x for details)
Chlorophyll a	6 depth horizons; total onto GF/F filter 1 horizon, size-fractionated	Fluorometry Onboard *Polarstern*	1x per week Daily	Collected, but unable to process onboard during Leg 1; will attempt processing on Leg 2 using bead-beating method
Pigment Biomarkers	6 depth horizons; total onto GF/F filter	High Performance Liquid Chromatography (HPLC)	1x per week	Collected and stored; standard depths.
Prokaryotes (Bacteria and Archaea)	8- 10 depth horiozons 6 – 10 depth horizons	Flow cytometry (FCM) DNA/RNA sequencing	1x per week	FCM samples collected and preserved; not run onboard DNA and RNA samples collected from standard depths in upper 300 m and

		Eco-Omics suite		additional collections at 4 depths below 1000 m
Eukaryotic microbes (protists)	6 depth horizons	Flow cytometry (FCM) DNA/RNA sequencing Eco-Omics suite Light microscopy	1x per week	FCM samples collected and preserved; not run onboard DNA and RNA samples collected from standard depths in upper 300 m and additional collections at 4 depths below 1000 m
Meiofauna / Microzooplankton	Water: 6 horizons Ice: bottom 10 cm section only	Water sampling DNA sequencing ROV Net	1x per week	Water column samples stored as light microscopy samples from 6 standard depth horizons in upper 200 m; Sea ice meiofauna samples collected near weekly from FYI and SYI
Meso/Macro zooplankton **Fish (polar cod)**	5 horizons Multinet: [2000-1000-500-200-50-0 m] Ring nets: integrated 0-100m and 0-1000m	Multinet Midi LOKI ROV Net	1x per week	Refer to section 6.x for details
Primary productivity (NPP) **Dark carbon fixation**	Water: 6 depth horizons Ice: 1 horizon, 2 ice types [bottom only]	14C-bicarbonate tracer 24hr incubation	1x per week	Not conducted during Leg 1
Net community production (NCP)	Seawater intake ~10 m depth horizon	MIMS; O2/Ar measurements	Continuous	Continuous run throughout Leg 1
Bacterial productivity (BP)	Water: 10 depth horizons Ice: 4 horizons	3H-leucine tracer 24 hr incubation	1x per week	Not conducted

Tab.6.1.2: Ecosystem project-specific process rate measurements.

Project-specific rate measurements	**Environments & Resolution**	**Method**	**Location: *Polarstern* and coring sites**	**Leg 1 Notes**

Nitrogen assimilation rates measurements:	Water: 3 depth horizons (alternating)	15N-Nxx tracer - nitrate, ammonium, N2, urea, AAs	1x per week	Refer to section 6.x
Community respiration L and D incubations	Water: 6 depth horizons Ice: not conducted	Optodes (Presens); 6-12 hr incubations	1x per week	Refer to section 6.x
Respiration, grazing, reproductive rates/indices	Water: tbd Ice: none	Grazing rates, reproductive indices	1x per week or 2x month	Refer to section 6.x

Tab.6.1.3: Summary of number of samples and seawater volumes processed per CTD-rosette cast.

Date	Cast depth (m)	# samples	Total volume of water (L)
2019-11-08	1000	91	231
2019-11-09	500	37	172
2019-11-14	4400	117	189
2019-11-14	200	42	288
2019-11-15	500	25	178
2019-11-21	4400	137	153
2019-11-21	200	26	288
2019-11-22	500	36	161
2019-11-23	1000	23	158
2019-11-28	240	26	288
2019-11-28	4400	142	152
2019-11-29	500	47	173
2019-11-29	300	26	288
2019-11-30	1000	23	198
2019-12-05	300	26	288

2019-12-05	4400	124	148
2019-12-06	500	42	165
2019-12-06	1000	23	158
TOTAL:		**1013**	**3676**

Sea ice discrete sampling

The Central Floe Observatory within the direct vicinity of *Polarstern* is a light-polluted area. Artificial light has strong effects on biological activities from single-celled organisms to fish. Therefore, most ecological measurements from snow and sea ice were conducted in a dark remote site located ~1.2 km from *Polarstern*. Upon initial surveying of the floe, we determined that the only suitable FYI region of sufficient size and accessibility was a minimum of 1km from *Polarstern.* In addition, we implemented precautions to prevent sampling within an artificially light polluted area to reduce light impacts on the evolution of biological properties and processes during the dark period. We used red-filtered light during our field collections and sample handling to reduce the effect of white light on organisms and their physiologies during polar night.

Within the dark remote region, to avoid disruption of nearby areas with repeat visits, each FYI and SYI time-series coring site was flagged to be as large as possible, which for SYI was was 200 x 100 m, and 500 x 150 m for FYI. For each coring event, a small plot (5 x 5 m) at each site was delineated and used to harvest the 25-30 cores. Within each 5 x 5 m plot, we conducted near-weekly sampling of co-located physical, geochemical, and ecological properties. Snow pit sampling occurred first upon arrival at each core plot. Following snow sampling, the main coring activities for the suite of time-series properties coordinated by each team commenced. This approach ensured that comprehensive information on snow and ice properties were derived from the same coring site for a specific time point in the time-series. Additionally, it allows us to link our measurements together across space and time. In addition to these primary ice coring plots, we established 2-3 SYI clone sites within the near–field area to support additional coring activities and to serve as backup sites should the primary SYI site be compromised or loss. Diagrams of the FYI and SYI sampling sites can be found in section 8.2 as Figures 8.2.x and 8.2.x.

Ecosystem coordinated variables collected from sea ice cores are summarized in Table 6.1.1. Ice cores used for Ecosystem properties are sectioned from the top and bottom, with a zero reference at the top. The bottom of the core is sectioned into 2 5cm sections, and then 10 cm sections thereafter. From the top, sections of 10 cm length are sectioned. Working from both ends, we create a variable length middle section in each of the cores. The variable length section is positioned in the middle of the core. Individual sections are pooled across 4 or 3 cores into 2 sets of Eco cores to be processed for a suite of properties. This approach ignores small spatial scale variability (cms) between cores, and averages properties over 1 – 2m of horizontal space in a given coring plot.

Core sections are pooled to support the number of variables, which need to be derived from each section. Onboard, 0.2 micron filtered surface seawater (FSW) was added to core sections in Whirlpak bags. For every centimeter of ice, 50 ml of FSW was added. During leg 1, surface seawater concentrations of nitrate were below 0.5 micromolar (see Figure 6.3.1), which was significantly less nitrate than contained within the planned artificial saline solution stock to be used for melting ice cores. Therefore, we determined that despite introductions of other

dissolved components from FSW, it was more important to limit the introduction of nitrate and phosphate to melting cores over the melt period (40-48 hrs). The use of artificial saline solution may be necessary for melting cores on following legs if we drift over waters with increased surface concentrations of nitrate and phosphate. It is possible for us to regularly monitor sea surface concentrations of macronutrients via onboard analyses of macronutrients.

The DIC core is processed differently. The DIC core is bagged in the field and processed onboard into 10 cm sections from the top in the -15°C ice physics lab container. The 10 cm sections are immediately placed within gas-tight bags and evacuated of ice using a small, motorized pump. Processing of the DIC core in the ice physics lab container occurs under white light. All core sections are melted onboard in the dark at room temperature (18 - 22°C) until the last piece of ice disappears. The melting time varies, but on average was between 40 - 48 hours. Until processing, melted ice is held in the dark at 0°C in a lab container. All cores and melted ice for ecosystem properties are processed in cold (0 – 4°C) and red light conditions to reduce negative effects on organismal physiology. The number of samples processed from sea ice for ecosystem properties is summarized in Table 6.1.4.

Tab.6.1.4: Summary of number of ecosystem coordinated samples collected from sea ice per sampling event.

Date	Number of samples for Eco properties	Number of nutrient samples	Totals
2019-10-28	104	36	140
2019-11-04	130	42	172
2019-11-11	168	44	212
2019-11-18	64 (FYI only)	20	84
2019-11-25	212	48	260
2019-12-02	202	48	250
2019-12-09	No sampling conducted; preparations for transition between Leg 1 and 2	0	0
2019-12-16	No sampling conducted; hand-over procedures	0	0
Total	6 events	238	1118

Preliminary (expected) results

A majority of Ecosystem properties are physical samples, which require further processing at shore-based laboratories. At present, physical samples are stored at respective temperature until further analysis. Specific results per project can be found in the following sections.

Given the commencement of routine sampling on leg 1 of both the water column and sea ice, we anticipate generating a number of data sets with temporal and spatial continuity during MOSAiC. These properties should provide synoptic weekly and/or daily snapshots of the physical and chemical environment, and provide insight into biological responses to these conditions.

Data management

All data are handled, documented, archived and published following the MOSAiC data policy (see APPENDIX). All final data will be published in relevant public open access data repositories. In general this is PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)). If data is published in alternative data repositories appropriate meta-data sharing and cross-linking will occur via the MOSAiC Central Storage and with PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)) according to the protocol agreed upon between these two archives.

References

No references.

6.2 ECOSYSTEM SCIENCE: ZOOPLANKTON ECOLOGY AND BIOLOGY

Objectives

1. Assess particle fluxes including optical imaging instruments, including a LISST, UVP, and LOKI. Couple particle flux estimates derived from imaging tools to discrete measurements of material fluxes generated from suspended POM and sediment trap collections of sinking POM to identify processes which result in high flux events.
2. Measure the temporal evolution of organismal distributions in sea ice and the ocean. Measure the spatial distribution of sympagic and planktonic biomass (e.g., ice algae, phytoplankton, microbes, micro- and meso-zooplankton) and determine their biodiversity.
3. Quantify biological rate processes that determine the inventories of elements and compounds across different trophic levels. Organic matter remineralization, microbial respiration, micro-zooplankton feeding and growth, and meso-zooplankton feeding, respiration, growth, and reproduction will be measured.
4. Determine standing stocks and distributions of microorganisms and animals to evaluate the physical-biological interactions that impact production, pelagic retention and vertical export below the halocline.
5. Evaluate impact of behavioral (e.g. vertical depth preferences and diel or ontogenic vertical migration) and life history (e.g. reproductive timing and overwintering strategies) patterns on nutrient fluxes, organismal abundance, and biomass in the ecosystem.

Work at sea

Zooplankton

Zooplankton work during leg 1 of MOSAiC started on October 28, with the first ice-coring event at the dark site. From this day on, the bottom 10 cm of ice cores drilled in first-year and second-year ice, respectively, were taken on a weekly basis, melted with the addition of filtered seawater and filtered on a 10 µm sieve. The contents were then preserved in 4% formalin (buffered with hexamethylenetetramine) to investigate the abundance and taxonomic composition of meiofauna organisms living in brine channels in the sea ice.

The pelagic zooplankton community in the CAO was sampled using a variety of nets and camera systems which were deployed through an ice hole on the starboard-side of *Polarstern*, using the ship's winch and crane (Figure 6.2.1). A submersible pump running inside the ice

hole during the casts prevented slush formation at the sea surface. To keep the zooplankton samples from freezing in the cold air, the cod ends of the nets were immediately pulled either into a heated shelter (Figure 6.2.2) or in front of an electric heater standing next to the ice hole. Here, the samples were transferred into beakers and carried back on board in an insulated box.

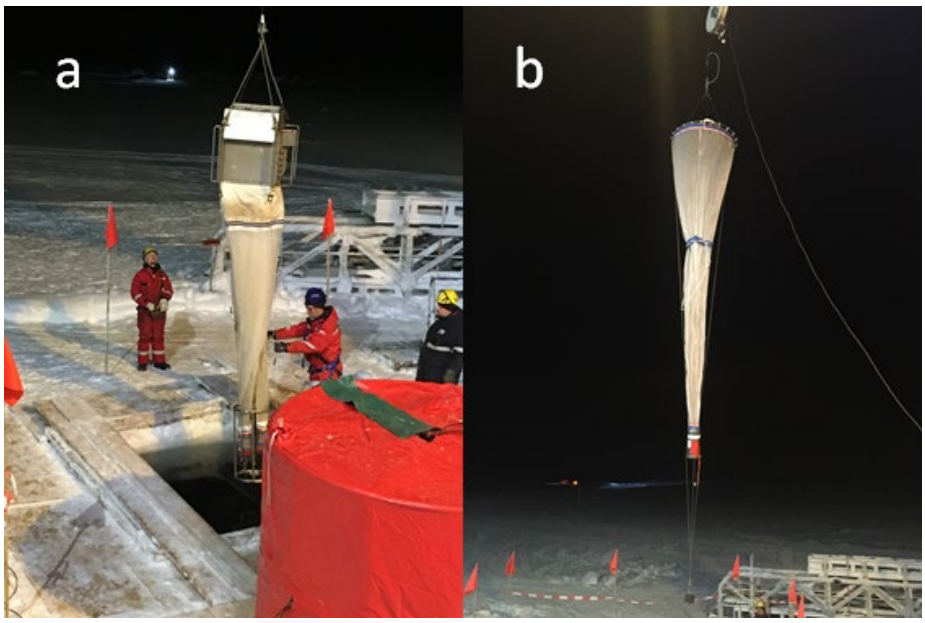

Fig.6.2.1: Deployment of the Multinet (a) and a ring net (b)

Fig.6.2.2: Sampling the net catch in the heated shelter. Photo: Marcel Nicolaus (AWI)

Weekly routine sampling was performed on Thursdays, Fridays and Saturdays, starting on November 7 and ending on December 7. Samples for analysing the large-scale distribution of meso-, micro- and macrozooplankton were obtained with a Multinet Midi (5 nets, 150 µm mesh size, 2000-1000-500-200-50-0 m water depth), a 60 cm ring net (53 µm, 200-0 m) and a 100 cm ring net (1000 µm, 1000-0 m), respectively (Table 6.2.1). All nets were operated at a speed of 0.5 m sec^{-1}. The samples were preserved in 4% buffered formalin and will be analysed in

the home laboratories at AWI Bremerhaven. To investigate the small-scale distribution of mesozooplankton in the upper 1000 m of the water column, the LOKI (Lightframe On-sight Key species Investigation), an optical plankton recorder, was deployed on a weekly basis. The LOKI was equipped with a 150 µm net and a high-resolution camera taking up to 19 pictures sec^{-1}. The underwater computer unit of the LOKI system immediately detected zooplankton organisms and particles in the pictures and saved clippings of these objects. In addition, a set of sensors measured depth, water temperature, conductivity, oxygen and fluorescence, which will allow us to relate the zooplankton distribution to the environmental conditions. A second optical device, the UVP (Underwater Vision Profiler), was mounted to the AWI CTD Rosette. During nine casts, including four deep casts to the sea floor (Table 6.2.1), the UVP took pictures at a frequency of 20 Hz. In those pictures, objects >2px were automatically counted and measured by the UVP system, while particles and organisms >80px were saved as vignettes to be analysed taxonomically.

The under-ice zooplankton community was studied in cooperation with the ROV team of the ICE group (see chapter 4). The ROV net consisted of a large 150 µm net bag and a small phytoplankton/gypsum net (10 µm mesh size) (Figure 6.2.3). Plastic lamellas on top of the net frame were used to scrape organisms off of the underside of the sea ice. Two ROVnet dive operations were performed (Table 6.2.1). During the first dive operation (6-118), a 15 min dive at 10 m depth was performed. Unfortunately, it turned out that the closing mechanism of the ROVnet did not work under water, making it impossible to sample discrete features further away from the ROV hole. During the second dive operation (10-113), we investigated zooplankton abundances over a 24 h cycle to determine whether these organisms migrate vertically even during the polar night. Every six hours, 15 min dives were performed at 0, 10 and 20 m water depth. All ROVnet samples were preserved in 4% buffered formalin for later taxonomical analyses.

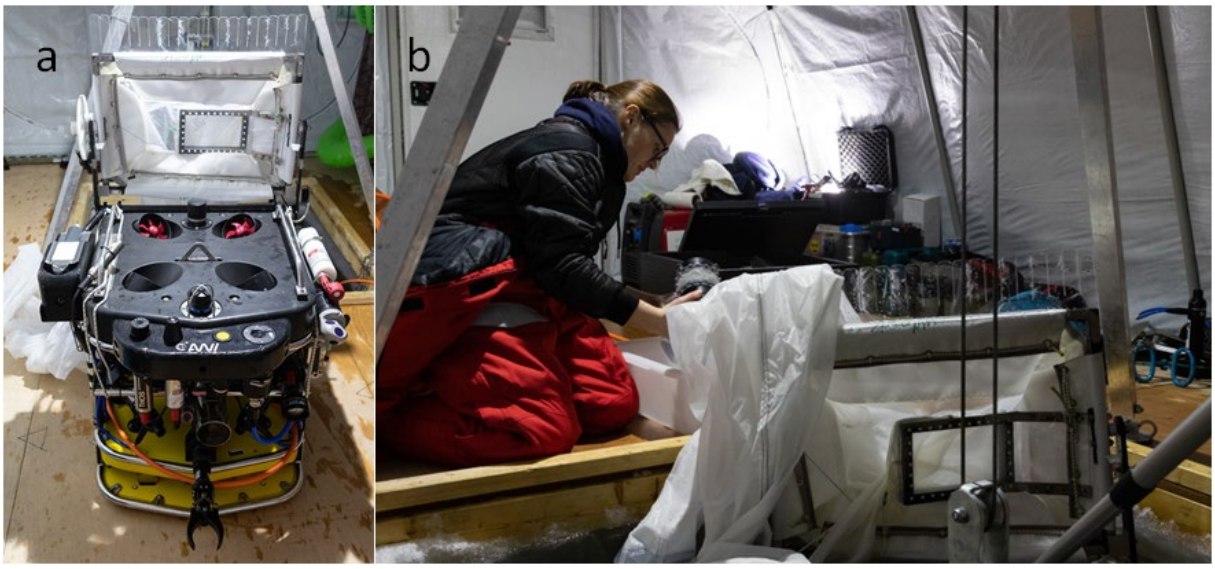

Fig.6.2.3: (a) The ROVnet mounted to the ROV „Beast“. (b) Sampling the ROVnet catch. Photos: Marcel Nicolaus (AWI)

Samples for analyzing total mesozooplankton biomass were taken on three occasions with a Multinet Midi (150 µm, 2000-1000-500-200-50-0 m). The content of each of the five nets was size-fractionated (>1000 µm, 1000-500 µm, <500 µm), filtered onto pre-weighted GFF filters and frozen at -20°C. On one occasion, also size-fractionated community respiration was measured. Zooplankton was incubated in glass bottles (0.5 to 2 L) for ~37 hours, while the oxygen content was monitored with an oxygen optode.

To assess the biochemical state of the zooplankton organisms during the Arctic winter, we performed additional net casts. 60 cm ring nets (150 µm) were deployed to 200 m depth (weekly) and from 2000-200 m depth (1x). Subsamples of the 200 m deep ring net catches were immediately preserved in 96% ethanol to investigate gutDNA in *Calanus* spp. From the remaining net samples as well as from the 1000 µm ring nets (see above), individual zooplankton organisms were sorted in a cold container (4°C). Target species included copepods (*Calanus hyperboreus*, *C. glacialis*, *Paraeuchaeta* spp., *Metridia longa*, *Spinocalanus magnus*, *Oncaea* spp.), amphipods (*Themisto libellula*, *T. abyssorum*, *Cyclocaris guilelmi*, *Apherusa glacialis*, *Eusirus holmii*, *Lanceola clausi*), euphausiids (*Thysanoessa longicaudata*), decapods (*Hymenodora glacialis*), chaetognaths (*Eukrohnia hamata*, *Parasagitta elegans*), ostracods and jelly fish (*Atolla tenella*, *Botrynema ellinorae*, *B. brucei*, *Sminthea arctica*, *Aglantha digitale*, *Aeginopsis laurentii*, *Solmundella bitentaculata*, ctenophores, siphonophores). For analysing trophic biomarkers (lipid class composition, fatty acid composition, bulk stable isotope composition, compound-specific stable isotope composition of fatty acids, highly branched isoprenoids), zooplankton organisms were photographed with a stereo microscope camera and deep-frozen at -80°C in pre-combusted glass vials. Organisms for determining CN and energy content were photographed and frozen at -20°C. Jelly fish were sorted completely from the catches and photographed for the ARJEL project of Charlotte Havermans. Part of the individuals were frozen in liquid nitrogen and thereafter transferred to -80°C to study transcriptomics. The remaining jelly fish were frozen at -80°C for abundance and biodiversity as well as for molecular diet and biomarker analyses. To investigate digestive and metabolic enzyme activities in *Calanus* spp., individuals were deep-frozen at -80°C. During the last sampling week of Leg 1, we also measured individual respiration rates in *C. hyperboreus* and *C. glacialis*.

The Multinet Midi was used to obtain depth-stratified samples (2000-1000-500-200-50-0 m). To test the hypothesis that *Calanus* spp. which undergo diapause during winter alter their extracellular cation concentration and pH in order to regulate buoyancy at depth, the pH in the hymolymph of *C. hyperboreus* from the different depth layers was measured with a NanoDrop, using HPTS as a pH-sensitive fluorescent dye. A subsample of the hemolymph was frozen at -20°C to measure the cation concentration.

Tab.6.2.1: Overview of net operations and zooplankton samples.

Event ID	Gear	Net #	Mesh size (µm)	Depth max (m)	Depth min (m)	Abundance	CN	Trophic biomarker	Enzyme activity	Community respiration (S/F)	Biomass (S/F)	Jellyfish (ARJEL)	GutDNA	Energy content	Gut content	Individual respiration	Extracellular ion/pH
2-68	UVP				912.6	x											
6-64	RN60	1	53	200	0	x											
6-79	UVP				506.7	x											
6-80	MNs	1	150	2000	1000	x											
6-80	MNs	2	150	1000	0	x											
6-81	UVP				2034	x											
6-86	LOKI		150	1000	0	x											
6-87	RN100	1	150	200	0		x	x				x	x				
6-118	ROVnet	1	150	10	10	x	x	x	x								

7-47	UVP				202.4	x										
7-48	RN100	1	150	200	0	x		x	x			x		x		x
7-49	UVP				4438	x										
7-54	MNs	1	150	2000	1000	x										
7-54	MNs	2	150	1000	500	x										
7-54	MNs	3	150	500	200	x										
7-54	MNs	4	150	200	50	x										
7-54	MNs	5	150	50	0	x										
7-56	RN60	1	53	200	0	x										
7-57	LOKI		150	1000	0	x										
7-67	MNs	1	150	2000	1000						x					
7-67	MNs	2	150	1000	500						x					
7-67	MNs	3	150	500	200						x					
7-67	MNs	4	150	200	0						x					
7-81	RN100	1	1000	1000	0	x	x	x				x		x		
7-82	RN100	1	150	200	0								x			
8-43	UVP				304.1	x										
8-44	RN100	1	150	200	0		x	x					x			
8-45	RN60	1	53	200	0	x										
8-46	UVP				4437	x										
8-48	RN100	1	1000	1000	0	x	x	x				x				
8-59	MNs	1	150	2000	1000	x										
8-59	MNs	2	150	1000	500	x										
8-59	MNs	3	150	500	200	x										
8-59	MNs	4	150	200	50	x										
8-59	MNs	5	150	50	0	x										
8-60	RN100	1	150	200	0										x	
8-72	MNs	1	150	2000	1000											x
8-72	MNs	2	150	1000	500											x
8-72	MNs	3	150	500	200											x
8-72	MNs	4	150	200	50											x
8-72	MNs	5	150	50	0											x
8-73	LOKI		150	1000	0	x										
8-77	RN100	1	150	200	0											
8-94	MNs	1	150	2000	1000						x					
8-94	MNs	2	150	1000	500						x					
8-94	MNs	3	150	500	200						x					
8-94	MNs	4	150	200	50						x					
8-94	MNs	5	150	50	0						x					
8-98	UVP				1035	x										
9-50	UVP				4358	x										
9-55	MNs	1	150	2000	1000	x										
9-55	MNs	2	150	1000	500	x										
9-55	MNs	3	150	500	200	x										
9-55	MNs	4	150	200	50	x										
9-55	MNs	5	150	50	0	x										
9-62	LOKI		150	1000	0	x										

9-66	MNs	1	150	2000	1000					x	x				
9-66	MNs	2	150	1000	500					x	x				
9-66	MNs	3	150	500	200					x	x				
9-66	MNs	4	150	200	50					x	x				
9-66	MNs	5	150	50	0					x	x				
9-75	RN100	1	1000	1000	0										
9-76	RN60	1	53	200	0	x									
9-81	RN100	1	150	2000	200		x	x	x			x		x	
10-42	RN100	1	150	200	0								x		
10-43	RN60	1	53	200	0	x									
10-49	MNs	1	150	2000	1000	x									
10-49	MNs	2	150	1000	500	x									
10-49	MNs	3	150	500	200	x									
10-49	MNs	4	150	200	50	x									
10-49	MNs	5	150	50	0	x									
10-61	LOKI		150	1000	0	x									
10-62	RN100	1	1000	1000	0	x	x		x			x			
10-80	RN100	1	150	450	150	x									
10-82	RN100	1	150	200	0		x								x
10-113	ROVnet	1	150	10	10	x		x							
10-113	ROVnet	2	150	0	0	x									
10-113	ROVnet	3	150	10	10	x									
10-113	ROVnet	4	150	0	0	x									
10-113	ROVnet	5	150	20	20	x									
10-113	ROVnet	6	150	10	10	x									
10-113	ROVnet	7	150	0	0	x									
10-113	ROVnet	8	150	20	20	x									
10-113	ROVnet	9	150	10	10	x									
10-113	ROVnet	10	150	0	0	x									
10-113	ROVnet	11	150	20	20	x									

Preliminary (expected) results

All samples will be analyzed at the home laboratories. A summary of the type of gear used to collect different zooplankton size classes is shown in Table 6.2.2. An additional summary of the number of individuals sorted from different types of zooplankton analyses is shown in Table 6.2.3.

Tab.6.2.2: Number of zooplankton samples per gear type.

Gear	Mesh size and depths	Number of samples
5 Multinet casts	150 µm, 5 nets, 2000-1000-500-200-50-0 m	22
5 Ringnet casts	53 µm, 200m	5
4 Ringnet casts	1000 µm, 1000 m	3
1 Ringnet cast	150 µm, 450-150 m	1
12 ROVnet casts	150 µm; 0, 10, 20 m	12
5 LOKI casts	150 µm, 1000 m	~ 70,000 pictures
10 UVP casts	4400 m, 1000 m, 500 m	~110,000 pictures

11 ice cores	bottom 10 cm, FYI+SYI	11

Tab.6.2.3: Number of individuals sorted per analysis type. Individuals sorted from 8 ringnets 150 µm, 3 ringnets 1000 µm, 1 ROVnet 150 µm, 4 Multinets 150 µm.

Organism Type	Number of individuals	Analysis Type
Jellyfish	164	Taxonomy and DNA
35 samples, assorted	107	Energy content
1 sample, assorted		Gut content
Zooplankton all	45 filters	Biomass
Copepods	120	Enzymes
Copepods	48 samples	Extracellular ion concentration
Copepods	25	pHe
Assorted	543	Carbon and nitrogen
Fish	47 samples	Histology
Assorted	342	Trophic biomarkers
Copepods	4 samples	Gut DNA

Data management

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

References

No references

6.3 ECOSYSTEM SCIENCE: NUTRIENT BIOGEOCHEMISTRY

Objectives

Produce an annual mass balance of the cycling of macro and micronutrients across the sea ice-water interface. Characterize vertical fluxes of nutrients in combination with nutrient tracer assays to understand carbon and nitrogen recycling pathways by microbes in sea ice and seawater. We aim to measure the progressive concentration of nutrients, including iron, in sea ice over the ice formation season.

Work at sea

Samples collected from sea ice, snow, brine and seawater during Leg 1 of the MOSAiC expedition were analyzed onboard the R/V *Polarstern* over the course of ~3 months. Sample analysis was accomplished using a 5-channel Seal AA3 autoanalyzer. The instrument measured nitrate, phosphate, nitrite, silicate and ammonia across all five channels simultaneously.

Preliminary (expected) results

In total, six CTD were realized using both the small portable winch at OC (1 cast) as well as the *Polarstern* OZE rosette (5 casts). Approximately 150 unfiltered samples were analyzed (Figure 6.3.1). An example of the results from the first leg are presented in Figure 8.x.x for

nitrate and phosphate and are compared to results collected in this general area during PS94. Results suggest that the data collected during leg 1 of the MOSAiC campaign are of sufficient quality to suggest that the water column has not changed significantly during the past 4-5 years. A second set of seawater samples from these same CTD casts were also collected (and immediately frozen) for total nitrogen (TN) and total phosphorus (TP) analysis. Analysis of these samples will be performed at the Alfred Wegener Institute in Bremerhaven, Germany in the coming months. A frozen sample for nutrient analysis will occur alongside the TN/TP measurements to validate the results that were determined at sea.

Over 300 sea ice, 50 snow and 80 brine samples were collected during leg 1 of the MOSAiC campaign. These samples were collected at both the first year (FY) and second year (SY) ice sites that were jointly established by both the sea ICE and ECO teams in late September 2019 (Figure 6.3.2). These locations were visited 7 times during leg 1 and nutrient samples were collected during each visit. Samples were collected in 5-cm intervals and were taken from the subsection allocated for salinity and oxygen isotope analysis. Samples were set to thaw immediately after returning from the field. The following morning, the samples were immediately syringe filtered through 25 mm (0.2 micron) Advantec cellulose filters. Snow samples from several horizons above the coring site were melted alongside the sea ice subsections. Samples were analyzed the same day using the same protocol as was used for the seawater samples. Opportunistic sampling for brine occurred during the Monday coring exercise but also during trips to the site to assess travel conditions and if the site had undergone significant fracturing or ridging during deformation events. Brine samples were collected by drilling a series of sack holes approximately 1-2 meters apart to a depth of ~30-50 cm and allowing the brine to accumulate in the hole for 15 to 20 minutes prior to drawing the sample into a syringe through a piece of Tygon tubing. Brine samples were analyzed alongside either the CTD or sea ice analytical runs as time and chemicals allowed.

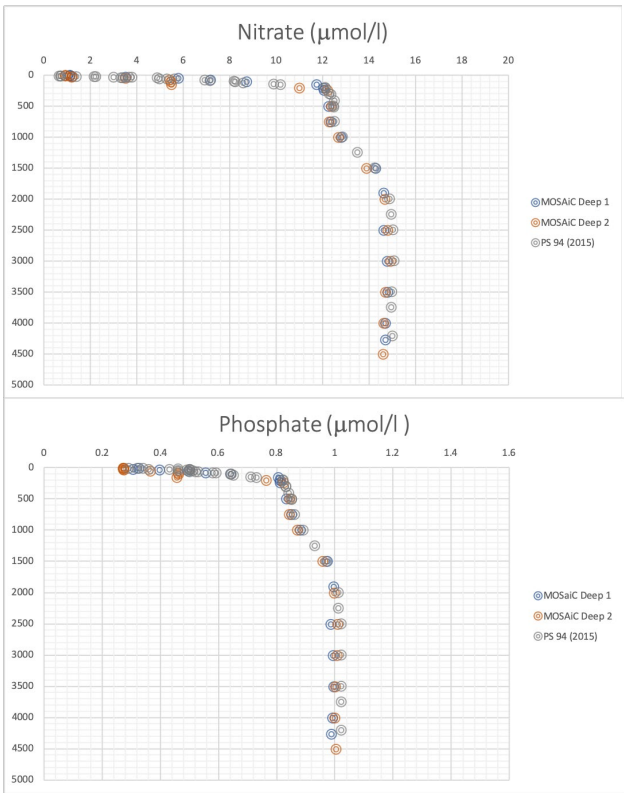

Fig.6.3.1: Seawater concentrations of nitrate and phosphate collected during Leg 1 of the MOSAiC campaign and compared to the results of a deep CTD cast collected from PS94 from the same general region of the Arctic Ocean. The y-axis is meters.

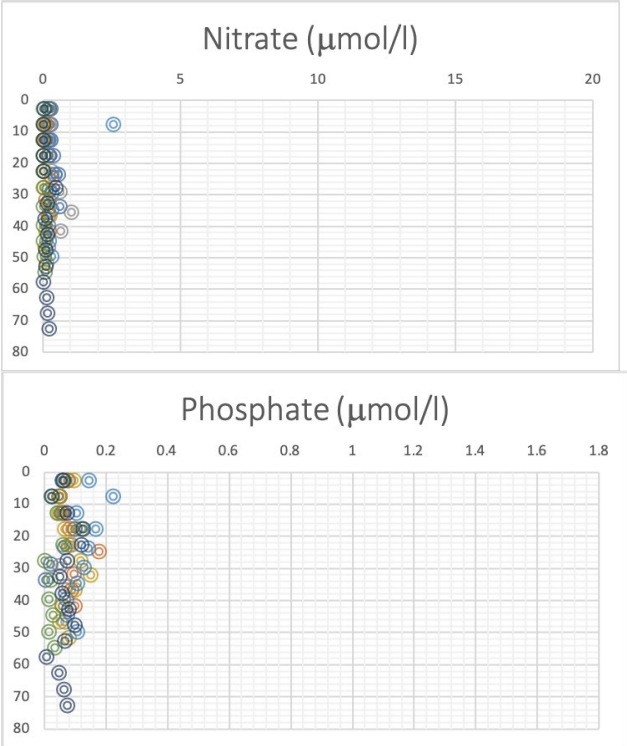

Fig.6.3.2: Sea Ice concentrations of nitrate and phosphate collected during Leg 1 of the MOSAiC campaign. The x- axis scale is set to match the oceanographic plots presented in Figure 8.x.x and the y-axis is in centimeters.

Data management

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

References

No references

6.4 UNCOVERING THE SEASONALITY OF SYMPAGIC AND PELAGIC MICROBIOMES AND THEIR METABOLIC FUNCTIONS IN THE CENTRAL ARCTIC OCEAN WITH EMPHASIS ON CARBON AND NITROGEN CYCLING

Pauline Snoeijs Leijonmalm[1], Allison Fong[2], L. Eggers[1,2]

(not on board:) Sinhue Torres-Valdes[2], A. Torstensson[1,3], J. Balmonte[1,3], S. Bertilsson[4], M. Buck[1,4]

[1]SE.SU

[2]DE.AWI

[3]SE.UU

[4]SE.SLU

Grant-No. NT-2018-04685 (Swedish Research Council VR)

Grant-No. FR-2018/0010 (Swedish Research Council FORMAS)

Grant-No. Dnr-2019-153 (Swedish Polar Research Secretariat SPRS)

Objectives

The CN-Project complements existing knowledge on the global marine microbiome with data from the Earth's least known large marine ecosystem, the permanently ice-covered Central Arctic Ocean (CAO). This includes not only metagenomic mapping of the full collection of genes in the microbial communities (archaea, bacteria, fungi, eukaryotes) living in the sympagic and pelagic microhabitats of the CAO, but also exploring gene expression, both in the field and during incubation experiments, and to relate the results to biogeochemical cycling and modelling. The participants of the CN-Project will - in experimental incubations - measure microbial C and N uptake by using stable isotope tracers in combination with single-cell transcriptomics and metatranscriptomics. To be able to relate the experimental results to natural conditions, we will - in collaboration with a large group of international scientists - reveal the seasonal succession of microbial community composition (DNA - metagenomics) and expressed metabolic functions (RNA - metatranscriptomics) in the field during a full seasonal cycle, see the part of this chapter dealing with the MOSAiC ECO Core Programme.

Work at sea

During Leg 1 of MOSAiC, Pauline Snoeijs Leijonmalm and Allison Fong established the practical routines for the CN-experiments. During the coming four legs, the experiments will be carried out by Lena Eggers (Leg 2), Anders Torstensson (Leg 3), Allison Fong (Leg 4), and John Paul Balmonte (Leg 5). We sample 140-150 L of seawater that, spiked with different stable isotopes, is incubated at ca. 1 °C on board, both in light and dark conditions (Figure 6.4.1). We focus on two pelagic habitats (sampled from the large CTD), the chlorophyll maximum in the surface layer (or, if absent, 20 m of depth) and the temperature maximum in the Atlantic layer (or, if absent 300 m of depth), and one sympagic habitat, the immediate sub-ice seawater (sampled from the ice with a hand pump). If no samples can be taken from any of these habitats for safety or logistic reasons, the water for the experiment is taken from the *Polarstern* seawater tap in Container F4 at the F-deck.

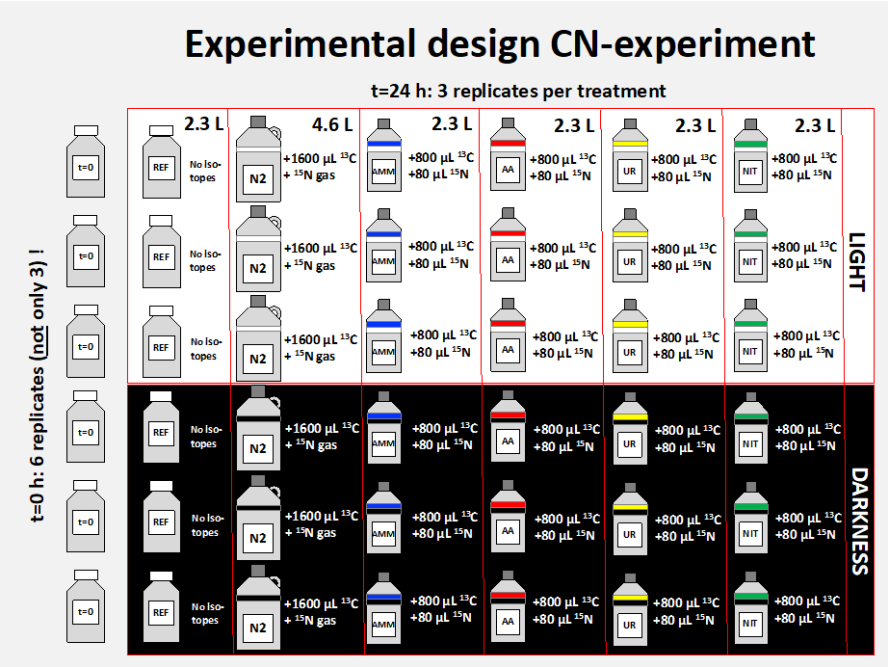

Fig.6.4.1: Experimental design of the CN-experiment as performed during MOSAiC.

In the course of one experiment, 118 sub-samples are taken for single-cell genomics, metatranscriptomics, mass spectrometry of stable isotopes, flow cytometry for cellular abundance and composition, as well as for inorganic and organic nutrients (Table 6.4.1). During MOSAiC Leg 1, eight full experiments were carried out (Table 6.4.2), as well as two tests for comparing Advantec glass fiber filters (pore size 0.3 µm) with Whatman GF/F glass fiber filters (pore size 0.7 µm) - the former filters are expected to retain more bacteria as a result of their smaller pore size. Furthermore, one RNA degradation test was performed to establish how much gene expression changes when seawater is kept in a dark container at 0 °C.

Tab.6.4.1: Overview of the 118 sub-samples taken during one CN-experiment

Working order	Sample type	DAY 1	DAY 2						Total
		t = 0	REF	N2	AMM	AA	UREA	NIT	
1	Single Cell genomics	3		6					9
2	MIMS			6					6
3	Nitrification				6				6
Make the Pajamas bottles									
4	Flow cytometry	4	4	4	4	4	4	4	28
5	Sterivex filters RNA	2	2	2	2	2	2	2	14
Rest of each experimental bottle									
6	Advantec filters	6	6	6	6	6	6	6	42
Samples taken from Carboy with the rest of the mixed water									
7	Inorganic nutrients	3							3
8	Organic nutrients	6							6
9	Sterivex filter DNA	1							1
Samples taken from extra Carboy(s) = has not been in mixing tank									
9	Sterivex filters DNA	3							3

Tab.6.4.2: Overview of the experiments performed during Leg 1

File no.	Date	Sampling time	Device	Path to MCS	Sensor Web-ID	Type of experiment	Device Operation ID
1	191107	14:30	Underway Water Sampling	platforms/vessel/polarstern/uws_ps/exdata/PS122-1_6-143	3220	Filter comparison 1	PS122/1_6-143
2	191109	Around lunch	CTD, shallow cast, 320 m	platforms/vessel/polarstern/ctd_sbe9plus_321/exdata/ PS122-1_6-79	3214	CN-experiment 1	PS122/1_6-79
3	191115	Around lunch	CTD, shallow cast, Chlmax	platforms/vessel/polarstern/ctd_sbe9plus_321/exdata/PS122-1_7-80	3214	CN-experiment 2	PS122/1_7-80
4	191119	10:00	Hand pump, sub-ice seawater	platforms/pack_ice/ice_ps/hand_pump/exdata/PS122-1_8-128	6181	CN-experiment 3	PS122/1_8-128
5	191119	10:00	Hand pump, sub-ice seawater	platforms/pack_ice/ice_ps/hand_pump/exdata/PS122-1_8-129	6181	Filter comparison 2	PS122/1_8-129
6	191122	Before lunch	CTD, shallow cast, 330 m	platforms/vessel/polarstern/ctd_sbe9plus_321/exdata/PS122-1_8-71	3214	CN-experiment 4	PS122/1_8-71
7	191124	14:06	Underway Water Sampling	platforms/vessel/polarstern/uws_ps/exdata/PS122-1_8-130	3220	RNA stability test	PS122/1_8-130
8	191124	14:06	Underway Water Sampling	platforms/vessel/polarstern/uws_ps/exdata/PS122-1_8-131	3220	CN-experiment 5	PS122/1_8-131
9	191129	Around lunch	CTD, shallow cast, Chlmax	platforms/vessel/polarstern/ctd_sbe9plus_321/exdata/PS122-1_9-67	3214	CN-experiment 6	PS122/1_9-67
10	191202	14:00	Hand pump, sub-ice seawater	platforms/pack_ice/ice_ps/hand_pump/exdata/PS122-1_10-138	6181	CN-experiment 7	PS122/1_10-138
11	191206	After lunch	CTD, shallow cast, Tempmax	platforms/vessel/polarstern/ctd_sbe9plus_321/exdata/PS122/1-20-60	3214	CN-experiment 8	PS122/1_20-60

For the field samples of DNA and RNA, with many scientists involved in sampling, analyses and bioinformatics, including all participants in the CN-Project, see the part of this chapter dealing with the MOSAiC ECO Core Programme. The CN-Project sponsors a significant part of the field sampling programme in the form of berths, consumables (Sterivex filters, GF/F filters) and equipment (peristaltic pumps, etc.).

Preliminary (expected) results

We expect to uncover microbial processes that take place during the half-year long polar night. In summer the focus is on processes related to the melting of sea ice which is increasing dramatically in the CAO as a result of global warming, e.g. the expansion of brackish and fresh water alters microbial community composition (Fernández-Gómez et al. 2019). We particularly target C and N metabolism in general, and will specifically test three specific hypotheses: (a) that diazotrophy (biological N_2-fixation) is a significant source of new nitrogen to the oligotrophic CAO marine ecosystem throughout the year, (b) that urea is an alternative substrate for ammonium oxidation and chemoautotrophic CO_2 fixation in the CAO, especially in winter and at low ammonium availability, and (3) that amino acids (AA) can be used as a nutrient source by microbial communities.

Except for the analyses of inorganic nutrients, no samples were analyzed on board. All samples from the experiments will be sent to Stockholm University and from there distributed for analyses at other laboratories. The molecular and bioinformatics analyses will use the

resources of the Swedish National Genomics Infrastructure (NGI) and the SciLifeLab Stockholm-Uppsala for the experiments. For the field samples, sequencing will take place at JGI (DOE) as granted for the joint MOSAiC genomics application (Mock et al., 2019), see the part of this chapter dealing with the MOSAiC ECO Core Programme.

Data management

The molecular data will be stored in specialized open international genomics databases.

All molecular data will be published in specialized open international genomics databases. All other data will be published via PANGAEA (World Data Center PANGAEA Data Publisher for Earth & Environmental Science (www.pangaea.de)). For data published data repositories other than PANGAEA appropriate meta-data sharing and cross-linking will occur via the MOSAiC Central Storage and with PANGAEA according to the protocol agreed upon between these two archives.

References

Fernández-Gómez B, Díez B, Polz M, Ignacio Arroyo J, Alfaro F, Marchandon G, Sanhueza C, Farías L, Trefault N, Marquet P, Molina-Montenegro M, Sylvander P, Snoeijs-Leijonmalm P (2019) Bacterial community structure in a sympagic habitat expanding with global warming: brackish ice brine at 85-90 °N. The ISME Journal, 13, 316-333. [https://doi.org/10.1038/s41396-018-0268-9]

6.5 MEASUREMENTS OF SUSPENDED PARTICULATE MATTER AND DYNAMICS

Musheng Lan[1], Jian Ren[2], Allison Fong[3], Ying-Chih Fang[3], Hailun He[2]
(not on board:) Jianfeng He[1]

[1]CN.PRIC
[2]CN.SIO
[3]DE.AWI

Objectives

The ultimate goal of this project is to estimate the export and sequestration of particles beneath the sea ice and consequently impacts on the sensitive ecosystems over the central Arctic. It is composed of three sub-objectives:

1. To obtain the novel characteristics of distribution, concentration of suspended particulate matter by deploying LISST-Deep instrument (Laser *In-Situ* Scattering and Transmissometry) profiles.
2. To address the sources and dynamics of particles by co-ordinately analyzing particle components and comparing with other influencing oceanographic and ecology parameters.
3. And to estimate the export and sequestration of particles beneath the sea ice and interactions with the sensitive ecosystems by recording spatial and temporal variations of particles as well as physical, chemical and biological processes in the water column.

Work at sea

Deployment in Ocean City

The LISST-Deep instrument was deployed together with CTD by mounting it under the frame of CTD rosette (Figure 6.5.1). LISST-Deep was placed horizontally to the bottom of the CTD frame with a cross-shape (like letter “+”) and deployed simultaneously with the other sensors with a profiling speed of 0.2 - 0.5 m s^{-1}. Standard CTD measurements were obtained with a

Sea-Bird Electronics 911*plus* CTD interfaced with a General Oceanics rosette with twelve 5-litre Niskin bottles.

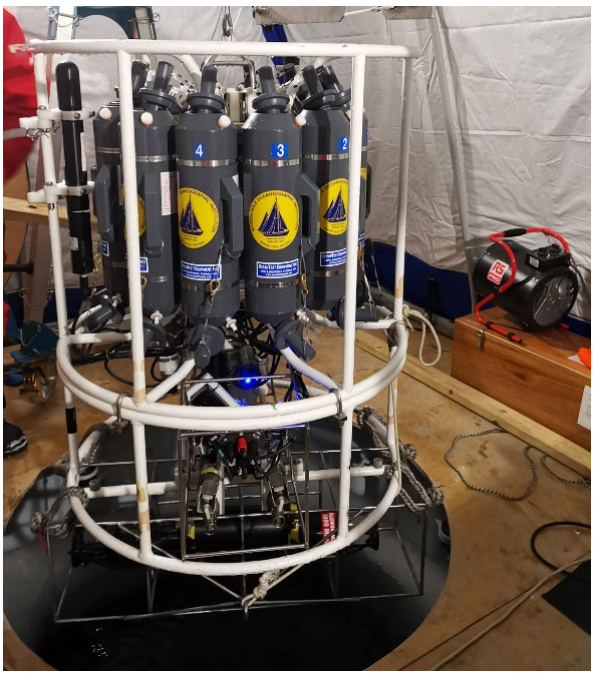

Fig.6.5.1: The configuration of LISST and CTD rosette before deployment

We set the LISST-Deep instrument operating mode as fixed sampling rate. That was the instrument would continuously measure 10 times in around 0.34s and stored average value as measurement results, then has 1 second sampling interval.

Particle volume concentration, and particle-size distribution measured by 32 ring-detectors (the inner rings detecting the largest particles and the outer rings detecting the smallest), corresponding to 32 classes in the range 1.5-250 µm, were determined with an autonomous LISST-Deep, which also measured beam attenuation, c at 670 nm-red, and pressure and Temperature as well with integrated sensors.Sensors were factory calibrated prior to the cruise. Optical windows were rinsed with MilliQ water and air-dried prior to each cast.

In this project, suspended particulate matter means the mass of total particles suspended in the water column, including both lithogenic and biogenic materials. To compare with LISST-derived particle size concentrations, water samples were collected from CTD and concentrated by inverse filtration equipment with 100-mm filters (0.8-µm pore size). Concentrated water samples were fixed immediately by formalin solution in the laboratory onboard *Polarstern*. These water samples will be detected with microscopy method to obtain the particle size distributions and components.

In total, 10 LISST profiles were performed in Ocean City from 5-November to 11-December range from 200-1000m during the MOSAiC Leg1 expedition (Figure. 6.5.2, Table 6.5.1). Although limited in number, these are the first LISST profiles ever acquired over the central Arctic Ocean beneath sea ice during autumn and winter.

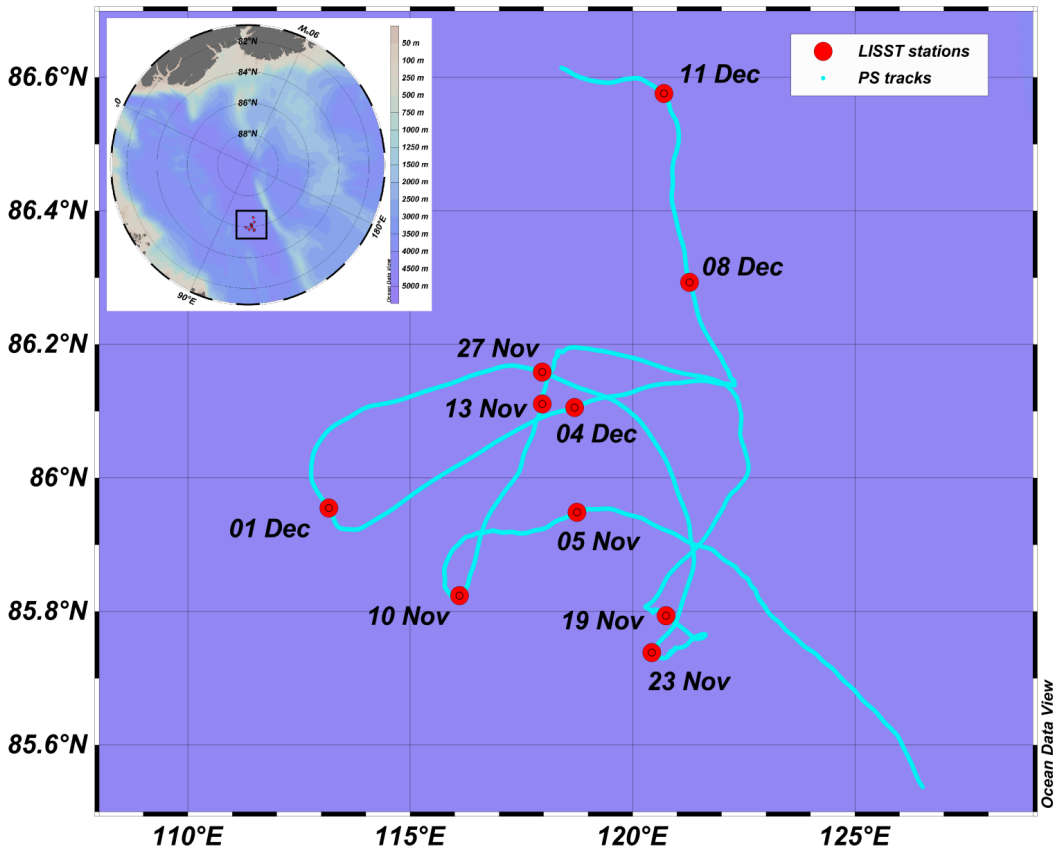

Fig.6.5.2: Map of LISST profiling stations in the central Arctic Ocean. Watery-blue line indicates the track of sea ice from 28 October to 12 December during the MOSAiC expedition

Tab.6.5.1: The information of LISST profiling Stations

NO.	Date	Activity	Latitude (ºN)	Longitude (ºE)
1	2019/11/5	PS122/1_6-18	85.948	118.752
2	2019/11/10	PS122/1_6-123	85.823635	116.111647
3	2019/11/13	PS122/1_7-42	86.110892	117.973391
4	2019/11/19	PS122/1_8-17	85.793615	120.753999
5	2019/11/23	PS122/1_9-38	85.738189	120.435878
6	2019/11/27	PS122/1_8-98	86.158318	117.972393
7	2019/12/1	PS122/1_10-12	85.954781	113.177389
8	2019/12/4	PS122/1_10-34	86.105489	118.702339
9	2019/12/8	PS122/1_10-110	86.292892	121.285791
10	2019/12/11	PS122/1_11-25	86.575818	120.709984

Preliminary (expected) results

One year-round data of suspended particles are expected to be obtained by continuously deploying LISST instrument during entire MOSAiC expedition. Spatial and temporal variations of particles in different seasons as well as physical, chemical and biological processes in the water column will be recorded and analyzed to estimate the sources and dynamics of suspended particles as well as interactions with ecosystems over the central Arctic Ocean.

Figure 6.5.3 shows particle volume concentration of suspended particulate matter captured by LISST. It was the first profile performed in Ocean City on November 5. Our observations revealed that the total particle volume concentration exceed 2 µl/l during early phase of ice forming season and most particles are collected at up layers with depth < 200m. The LISST particle concentration distribution exhibits multimodal peaks in the ranges of 20-40, 60-80 and 140-180m. The total particle volume concentration of suspended particulate matter in most deeper-layers (>200m) in the water column was less than 0.2 µl/l.

Figure 6.5.4 shows spatial and temporal variations of particle concentrations beneath sea ice during MOSAiC leg1 expedition from November 5 to December 11. Through the image reconstruction made by profiling and time series data, it is apparent that suspended particles decreased sharply at sea ice forming season during November.

In order to validate the findings from this study, additional measurements and parameters should be considered. Additional water samples and physical properties (e.g. temperature, salinity, density and current) and biological activities (e.g. biomass and habits) will be analyzed and coupled since they play significant roles in controlling the concentration and distribution and dynamic transports of particles such as settling and suspension.

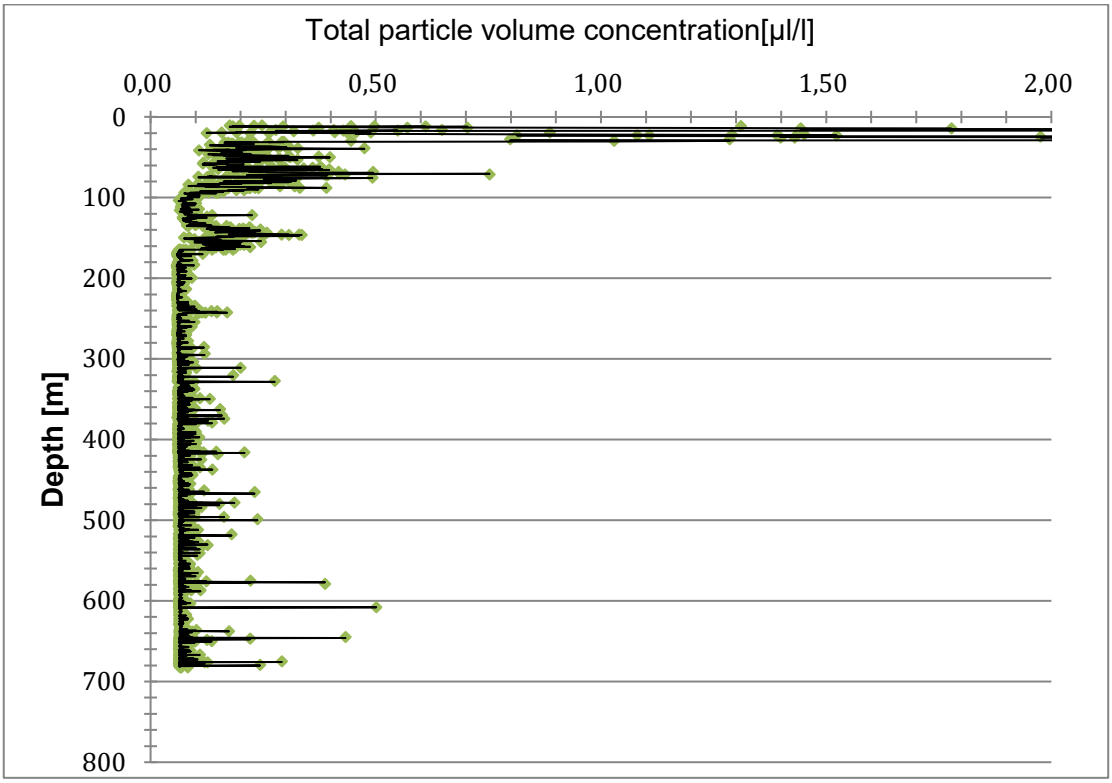

Fig.6.5.3: Profile of total particle volume concentration distribution performed on 5-November

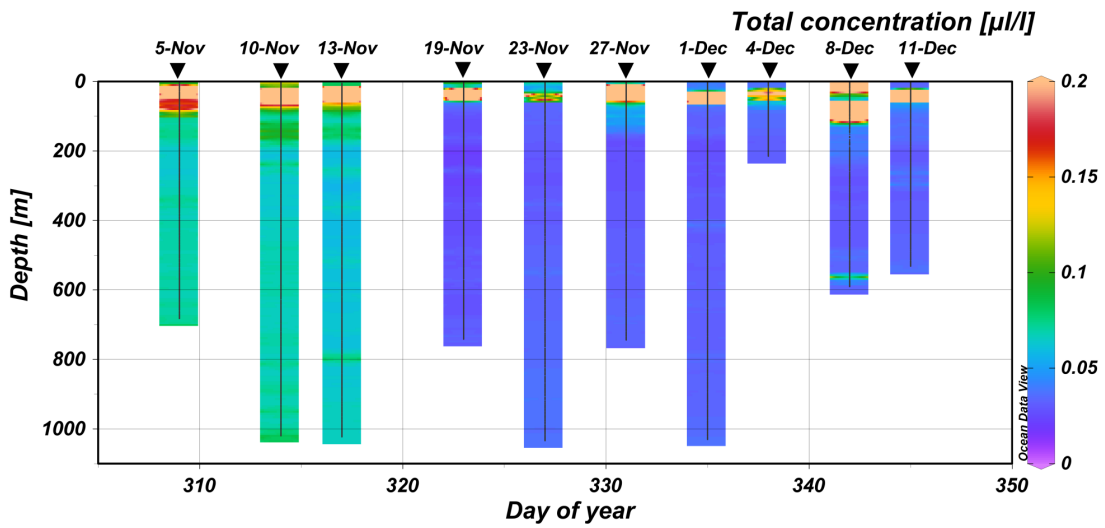

Fig.6.5.4: Profiles of particles from beneath the ice floe during MOSAiC Leg1

Data management

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

References

No references.

6.6 ANNUAL CYCLE OF PARTICLE EXPORT FLUXES IN THE CENTRAL ARCTIC OCEAN

Jian Ren[1] [1]CN.SIO

(not on board:) Jianfang Chen[1], Haiyan Jin[1]

Objectives

The overall aim of the project is to evaluate the alteration of the biogeochemical cycles and ecological systems in the changing Arctic by:

1. Collecting the year-long sinking particle flux from the bottom of sea ice to investigate the seasonal export pattern of total organic carbon (TOC), total nitrogen (TN), biomarkers (IP_{25} and phytosterols) and phytoplankton (diatoms) in order to assess the carbon cycle in the central Arctic Ocean.
2. Recording spatial and temporal distribution of nitrate, which is deficient in the Arctic Ocean (Yamamoto-Kawai et al., 2006), to estimate its impact on primary production and the carbon cycle as well as to predict its changing trend and corresponding ecological consequences in the warming Arctic.

Work at sea

Deployment of the sediment trap.

The sediment trap was deployed at ~200 m water depths in the Dark Site on 25th October 2019. The ice tethered mooring system is composed of a McLane sediment trap with 21 cups, a current meter and an ice buoy with the GPS device (Figure 6.6.1 and 6.6.2).

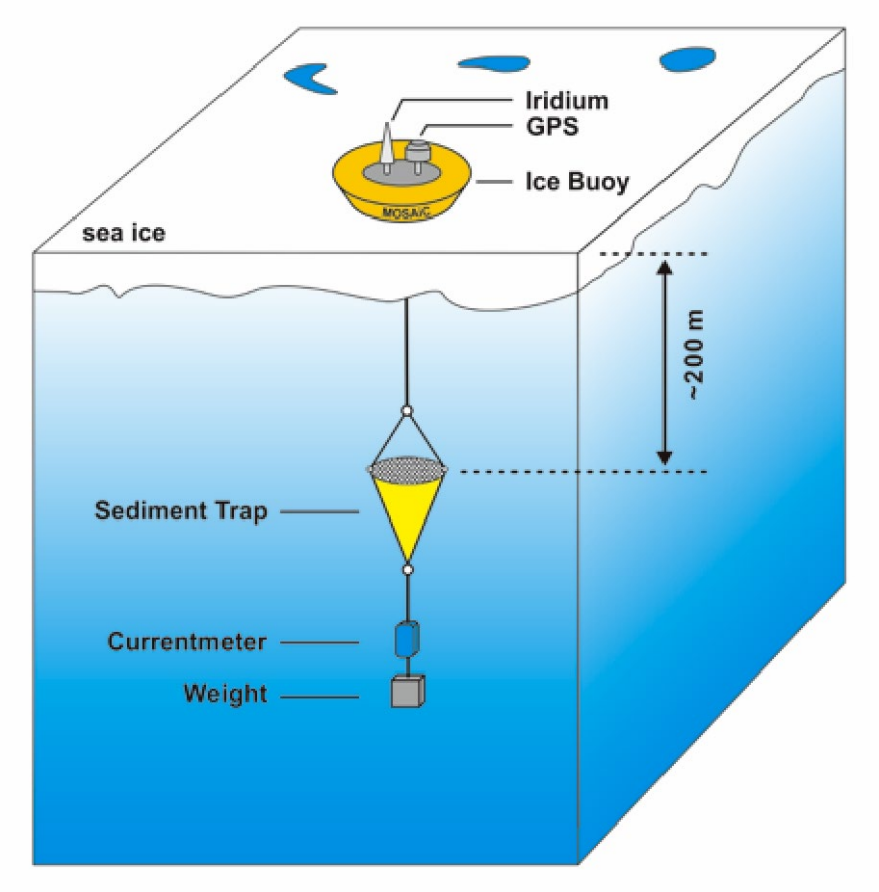

Fig.6.6.1: Schematic diagram of the configuration of the ice tethered sediment trap.

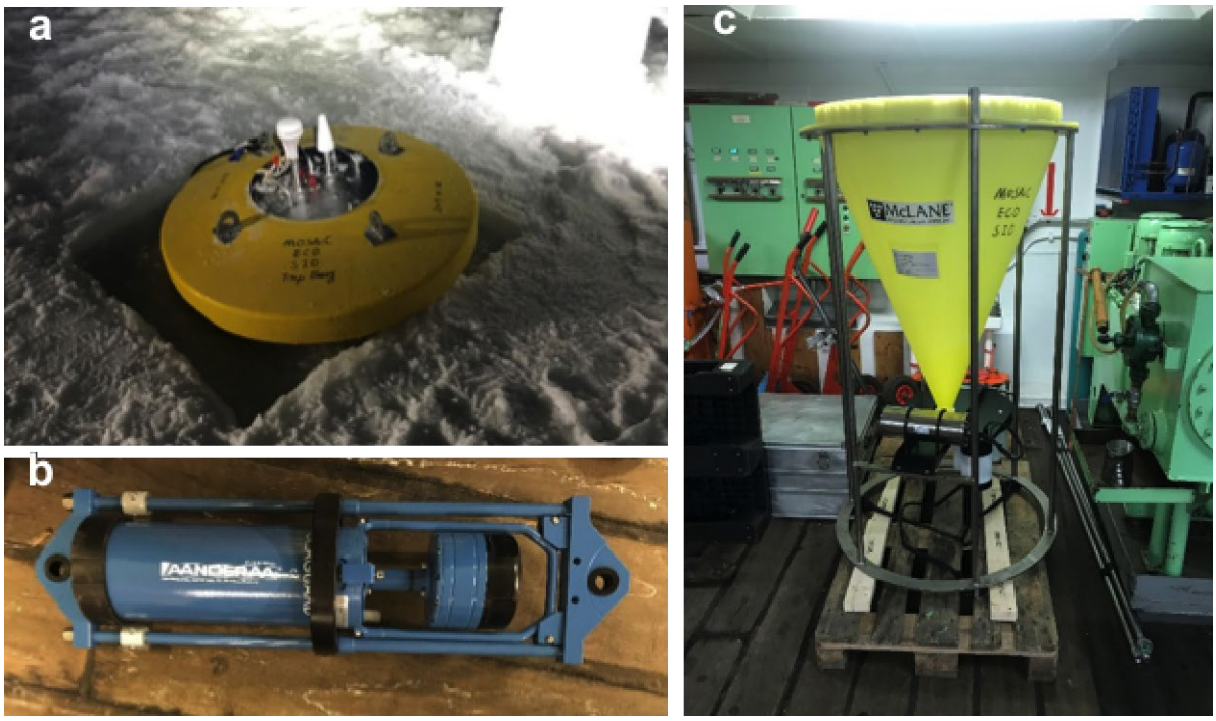

Fig.6.6.2: a) Ice buoy with GPS/Iridium; b) Aanderaa current meter; c) McLane sediment trap

The particle samples are generally collected every 15 or 16 days (depending on the month) except December, January and February (Table 6.6.1). The sampling cups were filled with filtrated sea water and poisoned with $HgCl_2$ before deployment.

The GPS position information is transmitted over Iridium to the corresponding person on land every 6 hours, ensuring the recovery of the ice tethered sediment trap when sea ice cracks or melts.

Tab.6.6.1: Sampling setting of the sediment trap

Cup	Starts	Ends	Duration (days)	Cup	Starts	Ends	Duration (days)
1	10/27/2019	11/15/2019	20	12	06/01/2020	06/15/2020	15
2	11/16/2019	11/30/2019	15	13	06/16/2020	06/31/2020	16
3	12/01/2019	12/31/2019	31	14	07/01/2020	07/15/2020	15
4	01/01/2020	01/31/2020	31	15	07/16/2020	07/31/2020	16
5	02/01/2020	02/29/2020	29	16	08/01/2020	08/15/2020	15
6	03/01/2020	03/15/2020	15	17	08/16/2020	08/31/2020	16
7	03/16/2020	03/31/2020	16	18	09/01/2020	09/15/2020	15
8	04/01/2020	04/15/2020	15	19	09/16/2020	09/30/2020	15
9	04/16/2020	04/30/2020	15	20	10/01/2020	10/15/2020	15
10	05/01/2020	05/15/2020	15	21	10/16/2020	10/31/2020	16
11	05/16/2020	05/31/2020	16				

Submersible Ultraviolet Nitrate Analyzer (SUNA) Casts.

A SUNA has been attached to the CTD aboard R/V *Polarstern* (Figure 6.6.3). In total 8 casts have been accomplished since November 2019, ranging from 300 m to 1000 m water depths.

Fig.6.6.3: SUNA attached to the CTD of R/V Polarstern

Preliminary (expected) results

Expected results of the sediment trap

After the recovery, TOC/TN and corresponding stable carbon isotopes, biomarkers (fatty acids, IP_{25}, sterols etc.) as well as siliceous phytoplankton (diatoms, silicoflagellates etc.) from the sinking particle samples of the entire year will be analysed.

Data management

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

References

Yamamoto-Kawai M, Carmack E, McLaughlin F (2006) Nitrogen balance and Arctic throughflow. Nature, 443, 43.

6.7 UNCOVERING THE LARGEST BLIND SPOT ON THE MAP OF THE WORLD'S FISH STOCKS: MESOPELAGIC FISH AND THEIR ROLE IN THE CENTRAL ARCTIC OCEAN FOOD WEB

Pauline Snoeijs Leijonmalm[1], Anders Svensson[3], Nicole Hildebrandt[2]

(not onboard:) Hauke Flores[2], Barbara Niehoff[2], Guilia Castellani[2], Serdar Sakinan[4]

[1]SE.SU

[2]DE.AWI

[3]SE.SLU

[4]NL.WUR

Grant-No. European Commission Framework Contract EASME/EMFF/2018/003, SC 1.3.2.2(03/SI2.805469 (EFICA Consortium, Specific Contract 03)

Grant-No. Dnr-2019-154 (Swedish Polar Research Secretariat SPRS)

Objectives

No scientific data exists for pelagic fish populations in the Central Arctic Ocean (CAO), i.e. the deep basins outside the continental shelves. In the EFICA (European Fisheries Inventory in the Central Arctic Ocean) project we target fish in the water column from the surface down to ca. 800 m of depth. Our goal is to answer the following research questions: (1) Do pelagic fish occur in the CAO?, (2) To which species and populations do they belong?, (3) What are their numbers and biomass along the MOSAiC drift transect?, (4) What is their role in the CAO pelagic food web?, (5) What are their migration patterns?, and (6) How are the existing populations expected to change with further climate warming? Since the *Polarstern* is drifting with the ice, MOSAiC offers the possibility to collect a unique acoustic data set with one year of measurements targeting fish while crossing the CAO. Such data collection is impossible to achieve when an ice-breaker is moving through the ice because of the noise. Normally, fish studies combine acoustics with trawling, but trawling is impossible in an area covered by thick sea ice. Therefore, we collect fish samples with fishing gear deployed from the ice as well as through "citizen science" on board by fishing from the *Polarstern*'s moon pool. We also use a deep-sea camera system for visual under-water observations and will mine the MOSAiC genomic data sets for fish genes to answer the EFICA project's research questions.

Work at sea

General

During Leg 1 of MOSAiC Pauline Snoeijs Leijonmalm, Anders Svenson and Nicole Hildebrandt have established the practical routines and developed the detailed Standard Operation Protocols (SOPs) that will be the standard for the EFICA project work during the rest of the MOSAiC expedition. During the coming four legs, the work will be carried out by Giulia Castellani (Leg 2), Serdar Sakinan (Leg 3), Hauke Flores (Leg 4), and Barbara Niehoff (Leg 5). Besides the direct EFICA work concerning fish, the participants of the EFICA project are involved in collecting oceanographic data (salinity, temperature, nutrients, chlorophyll-*a*, etc.), food-web data (zooplankton composition and abundance), and molecular data (eDNA). These data are necessary for analyzing the fish data and interpreting the results.

Hydroacoustics

We turned on the EK80 and EK60 echo sounders of the *Polarstern* on 1 October 2019. The installed frequencies on the EK80 were until 15 November 38 kHz (GPT, CW mode), 70 kHz (WBT, FM mode), 120 kHz (WBT, FM mode), and 200 kHz (GPT, CW mode). The 70 kHz and 120 kHz frequencies were manually swopped between FM and CW mode every 24 hours. On 15-20 November the 120 kHz frequency was turned off because we discovered that it was constantly disturbing the 38 and 70 kHz transducers. On the EK60, the 18 kHz transducer is used for bottom detection at a low ping interval (Table 6.7.1), and since 20 November also the 120 kHz transducer is running on the EK60 (GPT, CW mode). After this change, we got significantly higher-quality fish data. After the thorough assessment that we made in this matter, the conclusion is that the 120 kHz transducer must remain on the EK60 during the rest of the MOSAiC expedition. There is no reason to change this; zooplankton abundance data we get from the 200 kHz transducer on the EK80 and the 120 kHz transducer on the EK60.

During Leg 1 of MOSAiC we had many problems with disturbances, especially from the hydrosweep. We cannot use the *Polarstern* acoustic data for fish analyses if we synchronize

with the hydrosweep because we will use the single target tracking method for fish data analysis. The pings from the hydrosweep cut through the tracks of the fishes and we cannot follow the tracks so that we cannot quantify the fish. After the thorough assessment that we made in this matter, the MOSAiC leadership decided that the hydrosweep will not be turned on during MOSAiC anymore; the EFICA project is a part of MOSAiC and geological sea-bottom studies are not.

New acoustic instruments will be installed during MOSAiC all the time. Until now, the two ADCP's (one on the ship and one on the ice) have been operating without disturbing our fish data. The ship's ADCP is running in stand-alone mode (not on the k-sync); running it via the k-sync would render less ADCP data and destroy our measuring series, so this should never be reprogrammed during MOSAiC. Especially when AZFP's will be installed on the ice on the following legs, care must be taken that they are far enough away from the ship to not disturb the EFICA fish-acoustic data.

Tab.6.7.1: Synchronization (k-sync) of the ping intervals for the EK80 and EK60 of *Polarstern*, as established during Leg 1. This cannot be changed, and no ionstruments can be addedhere, for the rest of the MOSAiC expedition (it would damage our fish data set; since we will use single target tracking, we would miss parts of fish). EK80 = 38, 70, 200 kHz; EK60 = 18, 120 kHz.

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
Seconds	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	6.5	59
Instrument	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK80	EK60	Only 2

Fish sampling

After the initial work at Leg 1, including testing methods of deployment (from one hole or two holes in the ice; the latter with the help of an ROV) and different sampling gears (long lines and nets), it is now established that fish samples for the MOSAiC time series will be collected by standard fishing with long lines at least once per week (first day = deployment, second day = retrieval + deployment, third day = retrieval). These standard long lines have 150 hooks of three different sizes. This was decided after evaluating the different methods tested during MOSAiC Leg 1, although based on very few successful fishing efforts with the chosen method. Other methods can still be tested, but only after the basic standard fishing for the actual week has been carried out, so that a basic time series throughout MOSAiC is secured. If the weather does not allow working on the ice, the time will be spent on fishing with rods from the moon pool.

Visual observations

The deep-sea camera system (FishCam) was deployed for the first time on 23 October 2019 at 375 m of depth at Met City. After two weeks, on 7 November the video stream stopped working and some days later we were struck by a heavy storm. It took some weeks to get the power back to Met City, but then the FishCam still showed the same failure. After many technical and software tests, and in close contact with the manufacturer, we found that the only possibility was to take up the FishCam, which happened on 7 December. Once on the ship, several improvements were made on the camera hardware and after this the video stream work again. One of the two fiber optic links was found to be broken and we repaired it, but since the system has two links it is not fully certain that this was the problem. The FishCam was re-deployed on 12 December, this time at 214 m of depth, and has been working fine since then. The last video files for Leg 1 were downloaded before we left the *Polarstern* on 18 December.

Environmental DNA

During the last month of Leg 1, we used the large CTD rosette to take water samples for DNA and RNA metagenomics analyses, see the part of this chapter dealing with the MOSAiC ECO Core Program. Within the EFICA project, we will mine the large metagenomic data sets that will be created by the MOSAiC Eco-omics group for fish and zooplankton genes.

Preliminary (expected) results

Altogether, ca. 3 TB of hydroacoustic data were collected during Leg 1 of MOSAiC (1 October - 15 December). A scattering layer of living organisms was always observed in the Atlantic water layer of the CAO, but with varying density and varying vertical distribution. The organisms in the fish size range (>-45 dB) had extremely low densities, with generally only a few organisms larger than 15 cm detected by the echo sounder every hour (Figure 6.7.1). Since the fish abundance is so low, and we have two types of recurring disturbances that must be corrected for manually, we will use single target tracking as our method for the acoustic data analyses.

The first recurring disturbance is the release of the grey water from the *Polarstern* every second day. Before the expedition it was announced that the grey water would be discharged once a week, but in reality this is more often. The ship needs to get rid of large volumes of (cleaned) fresh water every second day instead of every week. Before discharging this fresh water, salt is added from the system producing fresh water from seawater so that the discharges would sink. We see these discharges by density changes on the echo sounder at ca. 150 m of depth (Figure 6.7.2). Since the water is cleaned and salted, this should not have any large effect on the fish but it is a disturbance that will include a larger effort from us when analyzing the echo sounder data because manual elaboration of the disturbance is necessary.

The second recurring disturbance is that of fishing rods being used from the moon pool - the weights to lower the bait show up on the echo sounder - similar to a fish - and the data must be removed manually. This is a trade-off between the acoustic data collection and the “citizen science” part of the EFICA project. Fishing with rods disturbs the acoustic data, but without fish samples we cannot interpret the acoustic data. During Leg 1 it was evident that it is possible to catch fish via the moon pool.

The fishing activities from the ice during Leg 1 of MOSAiC started on 28 October 2019, after the installation of the Central Observatory on the ice floe. In the period 28 October - 2 December we deployed seven long lines and three 6 x 40 m standard monitoring nets (with sections of different mesh sizes). In total, we collected six fish during Leg 1, three with long lines, one with the ROV, and two through citizen science (Table 6.7.2). This low number of fish samples collected confirms the low fish abundance in the area as observed from the hydroacoustic data. The data taken from each fish were total length, standard length, total weight, evis, and weight, while samples were taken from stomach, hindgut, gonads, liver, muscle tissue, otoliths, fin clip, for further analyses at home.

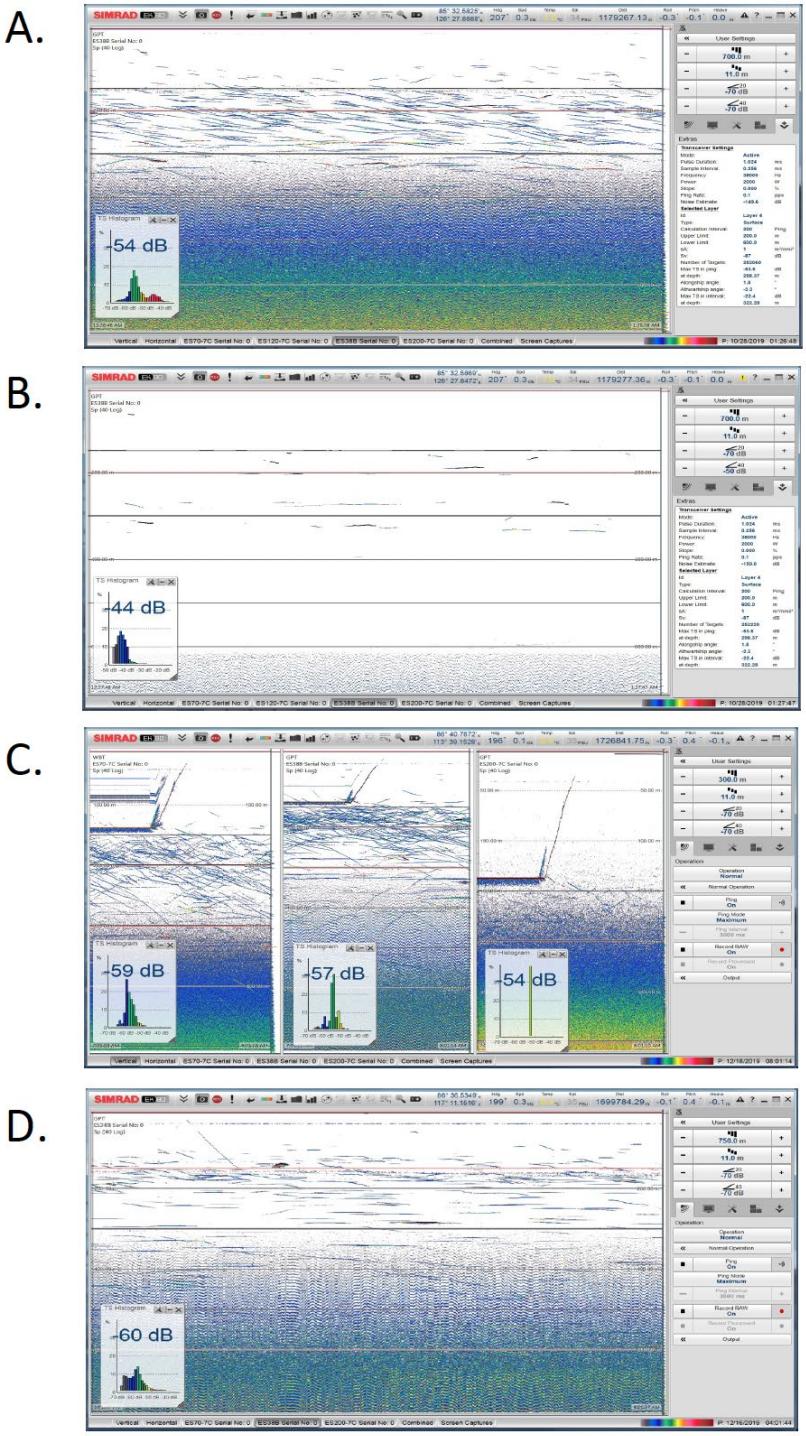

Fig.6.7.1: A. Echogram from 85º 33' N (1 hour) with a scattering layer of living organisms between 150 and 400 m cut off at -70 dB; most organisms are smaller than fish. B. The same echogram cut off at -50 dB; the organisms still visible may be fish, and their abundance is very low. C. Disturbance from the discharge of the grey water from the ship that happens every second day recorded at 70, 38 and 200 kHz. D. Disturbance from weights on a fishing rod in the moon pool at 38 kHz.

Tab.6.7.2: Overview of sampling efforts and fish samples taken during Leg 1 of MOSAiC, including the results of "Citizen science" in the case a fish was caught.

Deployment date	Retrieval date	Sampling method	Number of fish
2019-10-28	2019-10-29	Long line	2
2019-11-04	2019-11-05	Long line	1
2019-11-07	2019-11-08	Monitoring net	0
2019-11-11	2019-11-12	Long line	0
2019-11-18	2019-11-19	Long line	0
2019-11-19	2019-11-20	Long line	0
2019-11-24	2019-11-25	Monitoring net	0
2019-11-25	2019-11-26	Monitoring net	0
2019-12-01	2019-12-02	Long line	0
2019-12-02	2019-12-03	Long line	0
2019-12-07		Remote operated vehicle (ROV)	1
2019-10-31		Citizen science	1
2019-11-12		Citizen science	1
Total number of fish			**6**

Altogether, we collected 503 hours of video film in the three weeks the FishCam was operational (Table 6.7.3). Subjective tests were made by manipulating the lengths of the light and dark periods to find out if the light from the cameras would affect the organisms. The number of observations did not seem to be affected of the length of the light and dark periods. After this test period it was decided that during the rest of MOSAiC, the FishCam will record 55 minutes per hour with 5 minutes darkness in-between the recordings. This maximizes the total observation time. The video films will be analyzed at home.

Tab.6.7.3: Overview of the video recordings taken within the EFICA project in the periods 23 October - 7 November and 12 - 18 December 2019.

Number of video files	Minutes recording	Idle	Min/hour	Total hours
108	5	55	5	9
112	5	25	10	9
366	5	10	20	31
1070	15	15	30	268
204	55	5	55	187
1860				**503**

The Specific Contract SC03 between the European Commission and the EFICA Consortium concerns participation in the MOSAiC field campaign and the delivery of metadata of the type presented here. Concerning further elaboration of the collected data and samples, new Specific Contracts within the Framework Contract will be signed in 2020 (hydroacoustics, fish biology, population genetics, video analyses and bioinformatics). This work will be carried out at different partner institutes of the EFICA Consortium.

Data management

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

References

No references.

6.8 EVALUATION OF ICE NUCLEATING PARTICLES AND THEIR SOURCES IN THE CENTRAL ARCTIC DURING MOSAIC

Jessie Creamean[1] [1]EDU.CSU
(not on board:) Paul DeMott[1], Thomas Hill[1]

Background

The accelerated rate of warming in the Arctic is of great concern due to potential impacts that include release of greenhouse gases from permafrost, melting glacial ice contributing to sea level rise, and declining sea ice cover exposing the darker ocean surface. These processes induce positive feedbacks and contribute to further warming that affects climate globally. Clouds play a crucial role in regulating the energy reaching the sea ice and snow surfaces, but the magnitude of their effects on surface temperature is not well constrained in the Arctic. Aerosols are also an important contributor by serving as seeds for cloud particle formation, but even less is known about their overall impact and origin.

In particular, aerosols that serve as ice nucleating particles (INPs) are vastly understudied, especially above the central Arctic Ocean. Biological particles such as bacteria and components of soil organic matter are known to serve as the most efficient of INPs found in nature, facilitating cloud ice formation ≥ −5 °C. However, limited knowledge of the concentrations and sources of INPs in the central Arctic exists due to a dearth of measurements. In particular, previous studies in the central Arctic are limited to summertime measurements of INPs, and only speculate as to the sources. Marine biological productivity in the central Arctic has been shown to proliferate under certain environmental regimes (e.g., phytoplankton blooms in melt ponds, under-ice, and leads), but their contributions to airborne INPs are poorly understood

INPs have significant impacts on climate through cloud formation and modification of cloud particle properties, precipitation, and resulting surface radiation reaching the Arctic sea ice surface. INPs likely play a significant role in Arctic mixed-phase cloud (AMPC) microphysics and the resulting impacts of such clouds on the surface energy budget. To date, a full year's worth of INP measurements have not been conducted *anywhere* in the Arctic and *no* INP data exist from the central Arctic in the winter or spring, creating a significant gap in understanding AMPC microphysical processes. MOSAiC will provide the unique opportunity to execute these novel INP measurements.

Objectives

The overarching goal of this project is to achieve unprecedented characterization of INP abundance and sources (including biological) to evaluate their capacity to modulate cloud ice formation over the central Arctic. Specifically, the work is organized under three main objectives:

- Objective 1: Process size-resolved and total aerosol samples collected during MOSAiC for quantitative INP measurements and aerosol microbiological characterization to produce a high-quality dataset to be made available to the scientific community.
- Objective 2: Coordinate collection of seawater, surface microlayer (SML), snow, and sea ice samples for assessment of local INP sources to leverage complimentary aerosol INP measurements.
- Objective 3: Address a set of targeted scientific research questions based on current gaps in the understanding of INPs in the central Arctic:
    a. How do seasonal changes in sea ice and air mass transport influence INP abundance and sources in the central Arctic?

b. Are marine and sea ice biological processes a significant source of atmospheric INPs as compared to terrestrial sources?
c. Are open water environments such as leads and melt ponds viable sources of INPs over the sea ice and do such environments exchange INPs with the atmosphere?

Work at sea

The aerosol sampling activities during Leg 1 involved deployment of: 1) a size-resolved DRUM (DRUMAir™) and 2) two disposable sterile filter units (Nalgene™) per 72-hour sampling period, both for continuous collection of time-resolved aerosol samples during MOSAiC. These samplers were integrated into and outside of the second ARM Mobile Facility (AMF2) container and maintained by ARM site technicians. The DRUM collects aerosol particles at four size ranges (i.e., from 0.15 to > 12 µm in diameter with size cuts at 2.96, 1.21, and 0.34 µm). This size range covers a wide array of aerosols—particularly those that serve as INPs. Aerosols were impacted on clean perfluoroalkoxy substrate strips coated with petrolatum, a material tested by PI Creamean containing very few artifacts that interfere with INP analysis. The substrate strips were adhered to discs in each size chamber that rotate slowly over time, developing a "smear" of aerosol loading. After 24 hours, the discs rotated an additional 2 mm quickly, leaving a blank spot in between each daily sample. The DRUM continuously collected 24-hour samples for approximately 25 days without changing the substrates. The two filter units for multi-day integration of aerosols were comprised of a vacuum pump pulling air through polycarbonate filters (0.2 and 0.4 µm) fitted within sterile filter units covered by precipitation shields.

A portable aerosols sampler, called "C3PO", was deployed for approximately 4 days near a crack that opened in Met City during the beginning of Leg 1. C3PO is a robust, on-ice portable aerosol sampler in which the purpose is to collect aerosols for INP evaluation directly near open water sources. C3PO contains a miniaturized filter sampler (called the time-resolved aerosol particle sampler or TRAPS) that collected 6-hourly integrated total aerosol samples during Leg 1 and a handheld optical particle counter (OPC) that measured coarse particle size distributions in real-time. Both instruments were powered by a 12-V car battery and can operate continuously for up to 2 days.

Additional sampling activities included collection of seawater, sea ice, and snow to assess the local sources of INPs (i.e., called "source" samples) in sterilized Corning® centrifuge tubes. Specifically, seawater sampling entailed collection of a daily underway water sample, 10 depth horizon water samples from the weekly CTD deep cast (Thursdays), and 4 depth horizon water samples from a weekly experimental CTD shallow cast (Fridays). Seawater was also collected periodically from leads within the Central Observatory (CO) and near the dark site, at times collocated with C3PO, and from ice core holes each week at the first and second year coring sites. Sea ice melt water samples were collected from the core ECO ice core segments from pool A at approximately every other horizon. Fresh sea ice was also collected periodically from leads within the CO. Snow samples were collected during weekly snow pit sampling activities, at the coring sites each week, and during the C3PO deployment at Met City.

All samples collected during Leg 1 were stored frozen at –20 °C on *Polarstern* and transferred frozen to Colorado State University (CSU) where they will be stored frozen until analysis.

Preliminary results

Preliminary INP data are not available because all sample processing will be conducted offline at CSU. However, real-time data were obtained during the C3PO deployment and are shown Figure 6.8.1.

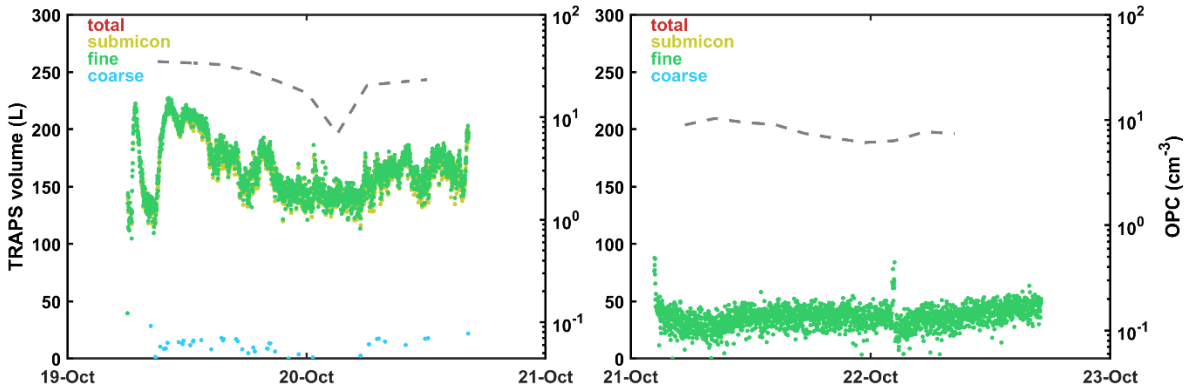

Fig.6.8.1: Preliminary data from the deployment of C3PO at Met City from 19 – 21 Oct 2019 (left) and 21 – 23 Oct 2019 (right). Data include the total volume of air that passed through each TRAPS filter sample (grey dashed line) and OPC particle concentrations at various size ranges of aerosol (colored dots), including total (0.3 – 17 µm in diameter), submicron (0.3 – 1 µm in diameter), fine (0.3 – 2.5 µm in diameter), and coarse (2.5 – 17 µm in diameter) size ranges.

The following Table 6.8.1 summarizes the types, frequency, and total number of each type of sample collected for INP (and DNA for the second filter unit) analyses during Leg 1 (starting 23 Oct 2019):

Tab.6.8.1: Types, frequency, and total number of each type of sample collected for INP.

Sample type	Frequency	Total # of samples
DRUM aerosol	24-hour	53
Filter unit aerosol	72-hour	34
Underway seawater	daily	46
CTD seawater (10 horizons nearest surface)	weekly	64
Lead seawater	episodic	7
Coring site seawater (first and second year sites)	weekly	8
Ice core	weekly	53
Fresh sea ice from lead	episodic	5
Snow pit (top, middle, bottom)	weekly	19
Snow near lead	episodic	4
Coring site snow (first and second year sites)	weekly	4
TOTAL:		297

In the upcoming months, samples will be subject to processing for INPs using two established immersion freezing ice nucleation techniques—the CSU drop freezing cold plate (DFCP) and CSU ice spectrometer (IS). A subset of the DRUM samples will be processed for time- and size-resolved INPs using the DFCP to manifest a semi-continuous time series of INPs during the annual cycle. One of the filter units will be processed for offline immersion INPs using the IS and one for DNA sequencing (i.e., amplification of select regions of the 16S and 18S genes) to assess the total INP time series and presence of possible biological ice nucleators. A further subset of samples from the first filter unit will be subject to heat and peroxide treatments to afford information on proteinaceous and organic INPs, respectively. A subset of the source samples will be processed using the immersion INP techniques for case studies during interesting events (e.g., when supporting measurements indicate convective aerosol

generation from melt ponds or leads, during episodes of high concentrations of INPs in the air, or when the offline biological characterization of the samples from the core ECO program indicate interesting events such as algal blooms).

Data management

Per the requirements of the agencies which have funded this project through two separate but related grants—the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) and Atmospheric Systems Research (ASR) programs—data will be made publically available on the DOE ARM data archive within 6 months of the end of the field deployment (i.e., data will be made publically available during spring 2021). DOIs will be communicated to PANGAEA for later access via the future MOSAiC Data Portal, according to the protocol agreed upon between these two archives. All data are further handled, documented, archived and published following the MOSAiC data policy.

References

No references.

6.9 QUANTIFYING MICROBIAL CONTROLS ON THE ANNUAL CYCLE OF METHANE AND OXYGEN WITHIN THE ULTRAOLIGOTROPHIC CENTRAL ARCTIC (JOINT WITH BGC)

Jessie Creamean[1]
(not on board:) Brice Loose[2], Jeff Bowman[3]

[1]EDU.CSU
[2]EDU.URI
[3]EDU.UCSD

Background and objectives

The overarching goal of this project is to undertake a comprehensive, mechanistic evaluation of oxygen and methane production, consumption, and transport in the central Arctic across the annual cycle. We will measure the rates of net community production (NCP), methane oxidation and production, bacterial respiration (BR) and bacterial production (BP) in the central Arctic from the air-ice interface through the photic zone. These measurements will be used to functionally constrain metabolic processes in two regional models of the Arctic and to produce model-based budgets of methane and net community production for the central Arctic. Through this effort we will better anticipate future change to the high Arctic marine ecosystem, and better understand the role of these processes in the current climate system. The proposed work will directly inform Questions 4 and 5 above of the MOSAiC Science Plan. To carry out these studies we will complete the following objectives:

- Make bi-weekly discrete profiles of seawater CH_4, CO_2 concentration, and stable isotope ratios using Cavity Ring Down Spectrometry (CRDS)
- Conduct continuous and bi-weekly sampling for microbial community structure (16S/18S rRNA gene analysis)
- Make discrete bi-weekly profiles of these same variables within sea ice cores
- Conduct bi-weekly measurements of BP and BR (bacterial and phytoplankton abundance and PP will be provided for these same samples by other ECO core measurements)
- Experimentally determine methane oxidation (MO) and methane production (MP), and evaluate the microbial community structure, gene expression, and oxidation potential using elevated methane in select incubations

- Identify patterns of expression for genes involved in methanotrophy, and use metatranscriptomics to identify genes differentially expressed under high methane conditions
- Through modeling, identify the microbial taxa and physicochemical conditions that best predict the key ecosystem functions of methane production, methane oxidation, BR, CR, BP, NCP, nitrification, and DMS production

Work at sea

The following Table 6.9.1 summarizes the samples collected during Leg 1 (starting 23 Oct 2019):

Tab.6.9.1: Sample collection

Sample type	Frequency	Purpose	Total # of samples
Underway seawater	daily	DNA filtration	46
CTD seawater at 6 horizons (PSW, chlmax, 100 m, 150 m, T_{max}, and 500 m)	weekly	DNA filtration	35
CTD seawater at 3 horizons (PSW, 150 m, T_{max})	weekly	RNA filtration	15
CTD seawater at 6 horizons (PSW, chlmax, 100 m, 150 m, T_{max}, and 500 m)	weekly	ambient CH_4	34
CTD seawater at 3 horizons (duplicates from PSW, 150 m, and T_{max})	weekly	CH_4 incubations	32
CTD seawater at 3 horizons (triplicates from PSW, 100 m, and 150m)	weekly	respiration (DO)	45
Ice core (bottom 10 cm at FYI site)	weekly	ambient CH_4	3
Ice core (bottom 10 cm at FYI site)	weekly	DNA filtration	3
TOTAL:			213

*PSW = Polar surface water

DNA and RNA filtration entailed filtering 1 L of seawater from either the underway system or CTD rosette and approximately 500 – 600 mL of sea ice melt from a bottom 10-cm ice core segment collected at the first year ice (FYI) coring site. Samples were stored at –80 °C (analysis was not conducted on board).

Ambient CH_4 and CH_4 incubation experiment samples were analyzed using a Picarro CRDS. Such samples were collected in gas-tight bags and included addition of 100 mL of Zero Air headspace (and 12 mL of a methane standard 1005 for the incubation sample duplicates only). Samples were stored in a water bath at 1 °C until analysis. Analysis involved 2 or 10 mL sampled headspace for incubation and ambient samples, respectively, drawing into a discrete sample isotope module coupled with the Picarro. Samples were run in duplicate and sometimes triplicate to achieve 5% or less uncertainty in $^{12}CH_4$ concentrations between the separate measurements. CH_4 incubations were carried out on a weekly to bi-weekly basis. The following Table 6.9.2 lists the number and dates (yy-mm-dd) of methane incubation samples collected. Dates shown in grey represent future planned dates for analysis.

Tab.6.9.2: Methane incubation samples.

Bag num	Net weight (g)	Collection date	CTD	Niskin	Depth (m)	t=0 date	t=1 date	t=2 date	t=3 date	t=4 date	t=5 date	Notes
021	813.54	19-11-02	PS122/1_5-59 CTD_SBE9plus_935	1	260	19-11-03	19-11-10	19-11-16	19-11-24	19-12-01	19-12-13	
022	805.55	19-11-02	PS122/1_5-59 CTD_SBE9plus_935	1	260	19-11-03	19-11-10	19-11-16	19-11-24	19-12-01	19-12-13	
023	798.07	19-11-02	PS122/1_5-59 CTD_SBE9plus_935	3	160	19-11-03	19-11-10	19-11-16	19-11-24	19-12-01	19-12-13	
024	792.23	19-11-02	PS122/1_5-59 CTD_SBE9plus_935	3	160	19-11-03	19-11-10	19-11-16	19-11-24	19-12-01	19-12-13	
025	811.37	19-11-02	PS122/1_5-59 CTD_SBE9plus_935	6	20	19-11-03	19-11-10	19-11-16	19-11-24	19-12-01	19-12-13	
026	804.44	19-11-02	PS122/1_5-59 CTD_SBE9plus_935	6	20	19-11-03	19-11-10	19-11-16	19-11-24	19-12-01	19-12-13	
027	815.03	19-11-09	PS122/1_6-79CTD_SBE9plus_321	15	320	19-11-10	19-11-17	19-11-23	19-12-07	19-12-21	20-01-04	
028	---	---	---	---	---	---	---	---	---	---	---	leak in bag
029	---	---	---	---	---	---	---	---	---	---	---	leak in bag
030	803.87	19-11-09	PS122/1_6-79CTD_SBE9plus_321	17	150	19-11-10	19-11-17	19-11-23	19-12-07	19-12-21	20-01-04	
031	805.84	19-11-09	PS122/1_6-79CTD_SBE9plus_321	21	40	19-11-10	19-11-17	19-11-23	19-12-07	19-12-21	20-01-04	
032	812.04	19-11-09	PS122/1_6-79CTD_SBE9plus_321	21	40	19-11-10	19-11-17	19-11-23	19-12-07	19-12-21	20-01-04	
033	---	---	---	---	---	---	---	---	---	---	---	leak in bag
034	855.88	19-11-15	PS122/1_7-80CTD_SBE9plus_321	4	240	19-11-16	19-11-23	19-11-30	19-12-13	19-12-28	20-01-11	
035	780.16	19-11-15	PS122/1_7-80CTD_SBE9plus_321	6	150	19-11-16	19-11-23	19-11-30	19-12-13	19-12-28	20-01-11	
036	791.68	19-11-15	PS122/1_7-80CTD_SBE9plus_321	6	150	19-11-16	19-11-23	19-11-30	19-12-13	19-12-28	20-01-11	
037	807.59	19-11-15	PS122/1_7-80CTD_SBE9plus_321	23	2	19-11-16	19-11-23	19-11-30	19-12-13	19-12-28	20-01-11	
038	833.80	19-11-15	PS122/1_7-80CTD_SBE9plus_321	23	2	19-11-16	19-11-23	19-11-30	19-12-13	19-12-28	20-01-11	
039	837.57	19-11-22	PS122/1_8-71CTD_SBE9plus_321	4	330	19-11-23	19-12-07	19-12-21	20-01-04	20-01-18	20-02-01	
040	---	---	---	---	---	---	---	---	---	---	---	leak in bag
041	818.76	19-11-22	PS122/1_8-71CTD_SBE9plus_321	18	150	19-11-23	19-12-07	19-12-21	20-01-04	20-01-18	20-02-01	
042	797.99	19-11-22	PS122/1_8-71CTD_SBE9plus_321	18	150	19-11-23	19-12-07	19-12-21	20-01-04	20-01-18	20-02-01	
043	846.55	19-11-22	PS122/1_8-71CTD_SBE9plus_321	23	10	19-11-23	19-12-07	19-12-21	20-01-04	20-01-18	20-02-01	
044	799.63	19-11-22	PS122/1_8-71CTD_SBE9plus_321	23	10	19-11-23	19-12-07	19-12-21	20-01-04	20-01-18	20-02-01	
045	770.49	19-11-29	PS122/1_9-61CTD_SBE9plus_321	3	320	19-11-30	19-12-13	19-12-28	20-01-11	20-01-25	20-02-08	
046	780.78	19-11-29	PS122/1_9-61CTD_SBE9plus_321	3	320	19-11-30	19-12-13	19-12-28	20-01-11	20-01-25	20-02-08	
047	748.29	19-11-29	PS122/1_9-61CTD_SBE9plus_321	6	150	19-11-30	19-12-13	19-12-28	20-01-11	20-01-25	20-02-08	
048	781.83	19-11-29	PS122/1_9-61CTD_SBE9plus_321	6	150	19-11-30	19-12-13	19-12-28	20-01-11	20-01-25	20-02-08	
049	749.10	19-11-29	PS122/1_9-61CTD_SBE9plus_321	23	5	19-11-30	19-12-13	19-12-28	20-01-11	20-01-25	20-02-08	
050	775.14	19-11-29	PS122/1_9-61CTD_SBE9plus_321	23	5	19-11-30	19-12-13	19-12-28	20-01-11	20-01-25	20-02-08	
051	806.31	19-12-06	PS122/1_10-60CTD_SBE9plus_321	4	350	19-12-07	19-12-28	20-01-11	20-01-25	20-02-08	20-02-22	
052	829.16	19-12-06	PS122/1_10-60CTD_SBE9plus_321	4	350	19-12-07	19-12-28	20-01-11	20-01-25	20-02-08	20-02-22	
053	788.80	19-12-06	PS122/1_10-60CTD_SBE9plus_321	18	150	19-12-07	19-12-28	20-01-11	20-01-25	20-02-08	20-02-22	
054	832.15	19-12-06	PS122/1_10-60CTD_SBE9plus_321	18	150	19-12-07	19-12-28	20-01-11	20-01-25	20-02-08	20-02-22	
055	799.32	19-12-06	PS122/1_10-60CTD_SBE9plus_321	23	10	19-12-07	19-12-28	20-01-11	20-01-25	20-02-08	20-02-22	
056	819.12	19-12-06	PS122/1_10-60CTD_SBE9plus_321	23	10	19-12-07	19-12-28	20-01-11	20-01-25	20-02-08	20-02-22	

Bottles containing seawater from the CTD rosette were stored in the dark at 1 °C immediately after collection. Respiration measurements were executed using a handheld FireString GO_2 dissolved oxygen (DO) sensor within 2 hours of collection (i.e., t0). Thereafter, DO measurements were conducted the following day from t0 (i.e., t1) and then every other day until reaching t5 – t6.

Preliminary results

Preliminary data include CH_4 and CO_2 isotopic concentrations from the ambient and incubation samples from the CTD and ice core samples, and dissolved oxygen concentrations from the

CTD samples specified in the sample table above. Indications of methane oxidation and respiration were observed from some of the sample subsets. Results and metadata from such measurements are provided on the MCS. All methane incubation bags were preserved for further incubation experimentation during subsequent legs.

Data management

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

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

References

No references.