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A strategy for meeting the needs for marine-based research in the Arctic

Deliverable 4.9. Report on cruise implementation, post cruise assessment and lessons learned

Submission of Deliverable

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1. Introduction

Transnational access to research icebreakers in the high Arctic lays at the core of the EU project ARICE. In the lifetime of the project, seven proposals (in eight cruises) were implemented on five of the ARICE consortium's vessels: PRV Polarstern (DE), RV Sikuliaq (USA), CCG Amundsen (CA), PRV Kronprins Haakon (NO) and IB Oden (SE). The cruise implementation was impacted by the COVID-19 pandemic in full, with cancellations and postponements of the ships' scientific programs in 2020 due to mobility restrictions. Only one proposal was implemented before the pandemic on board RV Sikuliaq (USA). All other cruises were affected by the restrictions in one way or the other.

In spite of this, the cruise implementation can be described as successful, not only from the point of view of the scientific teams, as reflected in D4.8, but also from the point of view of the vessel operators, as we will see in this deliverable.

2. Cruise implementation

The proposals implemented in the polar research vessels of the ARICE consortium were the following:

Cruise Name	PI Name	PRV	PRV Institution	Dates of the cruise	Cruise Area
Go-West	Hauke Flores	Sikuliaq	Alaska Fairbanks University (USA)	07.11.2019 – 02.12.2019	Beaufort and Chucki Seas
DEARice	Martin Schneebeli	Polarstern	Alfred Wegener Institute (AWI)	20.09.2019 – 12.10.2020	Central Arctic
NoTAC 2020	Rafael Gonçalves-Araujo	Kronprins Haakon	Norwegian Polar Institute (NPI)	24.08.2020 – 13.09.2020	Fram Strait
NoTAC 2021	Rafael Gonçalves-Araujo	Kronprins Haakon	Norwegian Polar Institute (NPI)	31.07.2021 – 20.08.2021	Fram Strait
VACAO	Tim Stöven	Oden	Swedish Polar Secretariat (SPRS)	25.07.2021 – 20.09.2021	Central Arctic
TRACE	Damian L. Arévalo-Martínez	Oden	Swedish Polar Secretariat (SPRS)	25.07.2021 – 20.09.2021	Central Arctic
ProMis	Birthe Zaencker	Oden	Swedish Polar Secretariat (SPRS)	25.07.2021 – 20.09.2021	Central Arctic
PeCaBeau	Vonk Jorien	Amundsen	University of Laval	09.09.2021 – 07.10.2021	Beaufort Sea

2.1.- GO-WEST

Infrastructure: RV Sikuliaq, USA
Type of access: TNA in person
Amount of access granted: 7 days
PI: Hauke Flores, Alfred Wegener Institute, Germany

Number of onboard participants funded by ARICE: 10

Number of remote participants: 0

Scientific fields: Biological Oceanography, Fisheries research, Polar Biology, Sea ice

Geographic area: Beaufort and Chukchi Seas
Cruise dates: 07.11.2019 – 02.12.2019, Nome, Alaska (USA) – Dutch Harbor, Alaska (USA)

Objectives:

Polar cod (*Boreogadus saida*), a key fish species in Arctic marine ecosystems, may be particularly susceptible to changing sea-ice habitats. It has been proposed that parts of the population get entrained with the growing sea ice in autumn, but how this happens and what proportion of the population becomes ice-associated is not known. The overall goal of the Go-West expedition was to test the hypothesis that entrainment of young Polar cod into the sea-ice habitat in the Chukchi and Beaufort seas during autumn is significant, and hence sea-ice association is an important survival strategy for Polar cod.

Short description of the work carried out:

The GO-WEST cruise was implemented within the expedition SKQ201923S with RV *Sikuliaq* (06 November – 02 December 2019). In GO-WEST we sampled Polar cod and its prey in the ice-water interface layer along with high resolution profiles of sea-ice and surface water properties with a Surface and Under-Ice Trawl (SUIT). We recorded backscatter of fish and zooplankton in the water column with the Sikuliaq's EK80 echosounder, and sampled pelagic communities with two midwater trawls (Methot trawl and IKMT) and vertical zooplankton nets (CalVET and ring net). A conductivity- temperature—depth probe equipped with a rosette water sampler (CTD) sampled vertical profiles of temperature, salinity and fluorescence and was used to collect water samples for the analysis for chlorophyll *a* concentration, nutrient concentrations, trophic biomarkers and harmful algae (HAB). During four ice stations, we sampled the sea ice for the same parameters (except nutrients), and performed hyperspectral light measurements needed to derive ice algae biomass from hyperspectral profiles obtained from a sensor mounted on the SUIT. In addition, we performed respiration measurements on abundant zooplankton prey species of Polar cod. Altogether, we completed 11 SUIT stations (1 in open water, 10 under ice), 4 ice stations and 3 midwater trawls. All SUIT deployments were successful, expanding Sikuliaq's capability of advanced scientific operations in ice-covered waters. Polar cod were caught at all SUIT stations, totalling 153 fish. Most fish appeared to be first- year juveniles between 6 and 8 cm in size, pending age determinations. Fish abundance increased with increasing ocean depth, sea-ice draft and abundance of the ice amphipod *Onisimus* spp.. The mesozooplankton community in the upper 50 m was dominated by the copepod *Metridia longa*. Respiration experiments indicated that *Metridia* and, surprisingly, *Calanus glacialis* from shelf stations were in an active metabolic state. Chlorophyll*a* concentrations were low (< 0.5 mg m^{-3}) in the water column. Conversely, visual inspection of ice core filters indicated that ice algal biomass had already begun to accumulate in the autumn sea ice. The trophic relationships between ice algae, zooplankton and sea-ice fauna and Polar cod will be analysed in detail based on hundreds of biological samples, including diet and trophic biomarker samples. Investigations of otolith microchemistry and population genetics studies on each sampled fish will help elucidate their origins and migration patterns. Preliminary results of this expedition support our hypothesis that juvenile Polar cod associate with sea ice in autumn and show that prey is available to sustain them at the onset of winter.

2.2.- DEARice

Infrastructure: PRV Polarstern
Type of access: TNA in person
Amount of access granted: 7 days
PI: Martin Schneebeli, WSL, CH
Number of onboard participants funded by ARICE: 5

Number of remote participants: 7

Scientific fields: Sea ice

Geographic area: Central Arctic Ocean

Cruise dates: 20.09.2019 – 12.10.2020, Tromsø (Norway) –Bremerhaven (Germany) (participation in MOSAiC Legs 1, 2 and 6).

Objectives:

The goal of this project is to provide continuous data of snow, ice and ecosystem processes, with a specific focus on snow and sea-ice ridges. Each member from the interdisciplinary project consortium has a specific strength (Schneebeli: snow physics, Granskog: sea ice ecosystem and physics, Pirazzini: solar radiation and albedo, Itkin: sea ice dynamics). By taking part in the MOSAiC drift experiment, that will provide observations over a full annual cycle, we will integrate highly detailed observations of snow, sea ice and ecosystem components across multiple scales. This will enable us to produce data sets that are critical to improve the process understanding of the Arctic sea-ice system, and thereof develop or improve parameterizations in numerical models and algorithms for the satellite-based detection of snow and sea ice. Our work provides added value to MOSAiC by coordinating several nationally funded projects, by coordinating activities and shared use of resources for optimized output beyond the duration of the field experiment. Our continuous observations of key properties will cover appropriate temporal and spatial scales to monitor short-lived but high-impact events and spatial heterogeneities that are critical for process studies and numerical model validations. We defined as key datasets to be measured snow on sea ice, sea ice ridges including its ecosystem, and sea ice albedo. The consortium has a unique combination of instrumentation and experience. Using terrestrial laser scanning, high-resolution penetrometry and X-ray microtomography and spectral high-quality albedo measurements we can measure the physical properties of the snow cover with unprecedented detail. The evolution of the ridge fauna and flora during an entire season will provide a much deeper insight into the development of this increasingly relevant habitat. We actively foster training and development of early career scientists (ECS) in an international and interdisciplinary environment.

Short description of the work carried out:

DEARice WP1: small-scale snow and sea ice physical processes

The overarching goal of the snow measurements is to characterize the spatial and temporal varying porous medium snow and sea ice. This was conducted with the view of improving snow models and in support of all MOSAiC inquiries from ICE, ATMOS, BGC, ECO, OCEAN and Remote Sensing. Our continuous observations of key properties cover appropriate temporal and spatial scales to monitor short lived but high-impact events and spatial heterogeneities that are critical for process studies and numerical model validation and implementation. The work was carried out mainly on the central observatory (CO), in an area assigned to snow measurements, and on different types of sea ice, including ridges. The team members conducted basic snow measurements (density, salinity, snow sampling, isotopic composition, specific surface area).

We used specialized equipment to carry out the following measurements:

- Weekly repeated terrestrial laser scans and GPR to develop a spatially resolved evolution of the snow accumulation and erosion process (cm spatial resolution) (see also WP3).
- SnowMicroPen (high resolution penetrometer) for fast retrieval of the vertical profile of snow stratigraphy, snow density and specific surface area. The instrument requires ~20 minutes to be installed and to collect a series of 3-5 consecutive profiles and was be used daily.
- X-ray microtomography on the ship on snow blocks sampled in the field and on cast samples (weekly to sub-weekly full vertical snow profiles up to 50 cm depth with sub-mm resolution)
- Near Infrared Photography (NIR) to characterize the specific surface area (SSA) of snow profiles as well as the snow surface. The installation of the instrument takes ~ 10 minutes. NIR was used daily on snow profiles and transects.
- FMI radiation station for continuous measurements of surface shortwave and longwave radiative fluxes.

DEARice WP2. Physical and ecosystem characterization of sea-ice ridges

Pressure ridges are formed by piling up of crushed ice blocks during sea ice convergence. Often the features also shear. While the ridge sail is the obvious surface part of the ridge, the submerged part –

ridge keel, is typically much larger and voluminous, taking up to 90% of the ridge volume. Both sails and keels are important surface roughness features that cause turbulence in the atmosphere and the ocean.

The work on sea-ice ridges focused on establishing a sea-ice ridge observatory (SIRO) on the CO, which was used to follow the evolution of a sea-ice ridge through legs II-IV, with leg I used for locating the site and deployment of autonomous systems (IMBs, thermistor strings, snow stakes, etc.). The SIRO was part of the core observational program throughout MOSAiC and made use of autonomous systems and a new ROV platform for interdisciplinary observations under sea ice. Regular weekly observations were performed from leg II onwards, and these included:

Continuous measurements of ridge temperatures and consolidation using IMBs (Ice Balance Buoys) (e.g. SIMBA with thermal inertia to detect ice or water) and thermistor strings deployed (on leg I or II) across the ridge, and snow depths using snow stages and IMB.

- Continuous measurement of ice fauna with Acoustic Fish and Zooplankton profiler (UiT, Gradinger) at ridge and a level ice site.

- Weekly drilling and ice coring of ridge for physical and biological parameters (including, ice density, ridge porosity, phytoplankton biomass, and plankton species diversity).
- Weekly mapping of ridge topography, at surface (lidar, roughly 1000x500 m2 area) and with multi-beam on ROV or AUV) - collaboration with AWI (Nicolaus), BAS (Wilkinson)
- Weekly mapping of ice fauna and flora using still camera and video on ROV and net tows for ice fauna with ROV below ridge and level ice (collaboration with Flores, AWI).
- Weekly snow depth mapping across ridge at SIRO and other ridges (on CO and also along transects in WP3), including detailed snow stratigraphy with the SnowMicroPen.

DEARice WP3. Large-scale snow and sea ice processes

To observe the large-scale variability in snow depth and sea ice thickness our team made observations on the CO and at the remote nodes of the MOSAiC DN. As part of this activity, we used weekly (at CO) and sporadic (at DN nodes) terrestrial lidar scans (about 500 m - 1 km diameter) that provide snow topography (roughness) at the centimetre-scale. Additional snow depth probing (Magnaprobe), and electromagnetic sounding (EM31, GEM-2) provide snow depth and sea ice thickness in the subsections of the scanned areas or dedicated transects.

The areas were designed in a way that they covered level and deformed ice and were distributed over various ice types (FYI, SYI, MYI, refrozen leads and refrozen ponds). Additional long transects (2-5 km) of snow depth and sea ice thickness took place sporadically if conditions permitted. To achieve a spatial resolution of sea ice thickness comparable to the laser scanner we collaborated with the ROV team (Nicolaus, Wilkinson) that will provide us with sub-meter scale resolution ice bottom topography from the multibeam system. Such collocations are only available at the CO.

To characterize the effect of surface heterogeneity (snow, bare ice, melt ponds, leads) on the surface albedo, our team operated a drone equipped with broadband and spectral radiometers and another drone with a camera for photogrammetric surface reconstruction. The drone-based surface albedo measurements were coordinated with the helicopter-based broadband radiation measurements (G. Birnbaum, AWI, Germany). The helicopter flights were planned within a regular weekly schedule and as immediate reaction in case of certain events, which considerably change the characteristics of the ice-ocean surface. The regular weekly flights aim at obtaining time series of surface albedo and surface radiation budget over fixed areas close to the central observatory and for instance between the super- sites of the distributed network.

2.3.- NoTAC

The cruise NoTAC took place in two seasons, 4 days in 2020 and 4 days in 2021. The season 2020 took place only as remote access due to the travel restrictions associated to the COVID-19.

NoTAC 2020

Infrastructure: RV Kronprins Haakon, NO
Type of access: TNA as remote access
PI: Rafael Gonçalves-Araujo (DTU-Aqua, DK)

Number of onboard participants funded by ARICE: 5
Number of remote participants: 7
Scientific fields: Biological Oceanography, Biogeochemistry, New technologies, Polar Biology

Amount of access granted: 4 days
Cruise dates: 24.08.2020 – 13.09.2020, Tromsø (Norway) – Tromsø (Norway)

Objectives:

NoTAC is an international collaboration focused on developing dissolved organic matter (DOM) as a tracer for Arctic water entering the Atlantic and exploring links between water mass origin and phytoplankton community composition. The project combines established tracer measurements with state-of-the art in situ sensor-based monitoring techniques to expand on existing techniques for tracing water mass origin in a major Arctic gateway, the Fram Strait.

The NoTAC project addresses four specific research objectives:

- Assess the variability of DOM composition and concentration within the water masses and develop an empirical model for retrieving water fractions from the optical properties of DOM to be validated with environmental radioisotope analysis;
- Link changes in microbial community (e.g., phyto- and microzooplankton) with different water mass origins;
- Calibrate and validate the use of bio-optical sensor-based data for water mass tracing;
- Determine the relative importance of photochemical- and microbial degradation on mineralization of Arctic organic carbon.

NoTAC requested 7 days of research time during the already planned FS2020 and FS2021 expeditions (ca. 3.5 day each year) on board the RV Kronprins Haakon to perform sampling at 21 oceanographic stations. The overall implementation took one additional day. At each station, rosette casts will collect hydrographic data (e.g., temperature and salinity) and water samples from discrete depths, while a set of sensors coupled to the system will acquire information on the physico-chemical and bio-optical properties of the water column. The planned activities in this proposal align with the proposed activities for the FS2020 and FS2021 expeditions.

Short description of the work carried out:

The FS2020 cruise on board R/V Kronprins Haakon in the Fram Strait took place between 24 August and 13 September 2020 and led by Senior Researcher Laura de Steur (NPI). Due to the COVID-19 pandemic, the 7 planned participants from the ARICE-funded NoTAC 2020 project were not able to join the cruise, since only NPI employees could take part in the cruise. Therefore, it was agreed that the NoTAC 2020 project would have a remote participation in the cruise and part of the sampling program would be carried out by the NPI participants. This, however, implied a reduction of the proposed NoTAC 2020 program, without the possibility to sample for a few parameters and to perform the incubation experiments. The samples and data collected during the cruise were shared and shipped to the NoTAC 2020 partners, who are currently analysing them.

NoTAC 2021

Infrastructure: RV Kronprins Haakon, NO
Type of access: TNA in person
PI: Rafael Gonçalves-Araujo (DTU-Aqua, DK)

Number of onboard participants funded by ARICE: 9
Number of remote participants: 3
Scientific fields: Biological Oceanography, Biogeochemistry, New technologies, Polar Biology

Amount of access granted: 6 days
Cruise dates: 31.07.2021 – 20.08.2021, Longyearbyen (Svalbard, Norway) – Longyearbyen (Svalbard, Norway)

Objectives:

NoTAC is an international collaboration focused on developing dissolved organic matter (DOM) as a tracer for Arctic water entering the Atlantic and exploring links between water mass origin and phytoplankton community composition. The project will combine established tracer measurements with state-of-the art in situ sensor-based monitoring techniques to expand on existing techniques for tracing water mass origin in a major Arctic gateway, the Fram Strait.

The NoTAC project addresses four specific research objectives:

- Assess the variability of DOM composition and concentration within the water masses and develop an empirical model for retrieving water fractions from the optical properties of DOM to be validated with environmental radioisotope analysis;
- Link changes in microbial community (e.g., phyto- and microzooplankton) with different water mass origins;
- Calibrate and validate the use of bio-optical sensor-based data for water mass tracing;
- Determine the relative importance of photochemical- and microbial degradation on mineralization of Arctic organic carbon.

Short description of the work carried out:

The FS2021 cruise on board R/V Kronprins Haakon in the Fram Strait took place between 31 July and 20 August 2021 (Figure 1) starting and ending in Longyearbyen, Svalbard, Norway. The cruise was led by Sen. Res. Laura de Steur (NPI). Due to the event of the COVID-19 pandemic and travel restrictions employed by the Norwegian government, part of the NoTAC participants had to undergo quarantine upon entrance in Norway. This is presented in more details in Section 1.1. Apart from the 7 participants (see participants list in Section 6) funded through ARICE, the NoTAC team counted with two more participants that joined the cruise with their own funding, Stine Zander (MSc student, University of Copenhagen) and Alexandra Cherkasheva (Postdoc, IOPAN) (Figure 2). The NoTAC team was responsible for the water sampling program during the cruise and performed incubation experiments and bio-otpical and radiometric sensor deployments.

2.4.- VACAO

Infrastructure: IB Oden, SE

Type of access: TNA in person
Amount of access granted: 2,33 day
PI: Tim Stöven, GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

Number of onboard participants funded by ARICE: 3

Number of remote participants: 7

Scientific fields: Chemical Oceanography, Carbon Cycle.

Geographic area: Central Arctic
Cruise dates: 25.07.2021 – 20.09.2021, Helsingborg, Sweden – Helsingborg, Sweden

Objectives:

The Arctic Ocean has the unique characteristic that here climate change becomes clearly more apparent than in any other region of the world. The elevated heat flux into the Arctic causes drastic changes in the multi-year ice coverage, which in turn influences the prevailing physical and biogeochemical processes. Especially the modification of the inflowing surface waters into the Arctic is an essential part of the global overturning circulation. The formation of deep water encompasses the transport of dissolved gases, such as carbon dioxide, into the ocean's interior. This process, named ventilation, is responsible for the storage of anthropogenic carbon in the world oceans and acts as buffer for greenhouse gas emissions.

1.1 Obtain and constrain the timescales of ventilation of the Arctic Ocean

Observations of a suite of transient tracers with different time-scales can resolve partly complicated transit time distribution (TTDs) that is a measure of ventilation and mixing. The most common tracers used for this are SF6, CFC-12 and other CFC's (Chlorofluorocarbons). These are anthropogenic tracers with a well-known atmospheric history. Along with the atmosphere being the source of transient tracers, there are also other important characteristics, such as a certain time dependency. Either a tracer has a time varying source with increasing concentration over time (SF6, CFC-12) or a decay rate (radioactive isotopes).

^{39}Ar is a tracer with a decay rate and an essential tracer when estimating the ventilation time scales of deep and intermediate water masses in the Arctic Ocean. It covers much longer time scales of 100-1000 years compared to CFC-12 and SF6. The latter two tracers are limited to young water masses that are either close to the surface or in high-ventilated deep waters. The new measurement technique of ^{39}Ar, namely Argon Trap Trace Analysis (ArTTA), now allows for standard oceanographic application due to the low amount of water needed for one sample (5-10L as of today) compared to the ~1000 L per sample using the Low Level Counting (LLC) method. With ^{39}Ar and the measurement of the Tracers CFC-12 and SF6 we are now able to determine the ventilation timescales of the complete water column from surface to bottom in every part of the Arctic Ocean. Ventilation time scales are given by the mean age of transit time distributions that are constrained by a multi tracer approach.

The saturation of all transient tracers is determined by surface conditions as well as by interior mixing processes. Measurements of stable noble gases (He, Ne, Ar, Kr, Xe) are used to determine possible saturation anomalies that arise during ice formation, water subduction and interior mixing. One focus is set to measure surface saturation during ice-formation. A second one concerns subduction/convection processes. Analyzing the saturation distortion for these different surface boundary conditions is of key importance for the correct input function of the tracers in polar waters and with this essential for constraining the ventilation timescales in the Arctic Ocean. The corrected input functions will reduce the uncertainty of the age distributions and improve the ocean circulation models.

Comparing the new tracer observations with historical data enables us to identify changes in the ventilation. This will be complemented by analyzing biogeochemical processes with regard to oxygen utilization rates and respiration processes such as formation of nutrient maxima.

1.2 Estimate the anthropogenic carbon content of the Arctic Ocean

The precise mean age is essential for the calculation of the anthropogenic carbon content of the Arctic. Here we use the constrained distribution function and the biogeochemical data from WP10 (such as DIC, TA, etc.) to back-calculate the distribution of anthropogenic carbon in the ocean. The obtained concentrations of anthropogenic carbon are then used to determine the column inventory of the Arctic Ocean, which provide new estimates on the carbon uptake capacity. The analysis of the current and historic tracer data then provides information on changes in the carbon inventory and thus about the carbon uptake rates during the last 40 years. These results are essential to quantify the buffer effect of the ocean for the increasing concentrations of greenhouse gases as well as climate damaging compounds in the atmosphere.

Short description of the work carried out:

After bording the ship on Saturday, 26th of July, we dircetly had a sayfty/fire instruction and evacuation training from the 2nd Officer on board. After leaving the harbour of Helsingborg on Sunday, 27th of July, the Instruments were set up and started in the laboratory. During the Transit to the first localized station (81°13.812’N/18°29.444’E) toolbox meetings took place concerning all the different work areas, including safety instructions. These areas were, i.e. laboratory work, CTD work, working on ice. Additionally all working groups set up their measuring instruments and prepared for the research.

Arriving to the research area on the 2nd of August, different operations occurred at each station, from CTD operations over different nets and helicopter stations to ice stations. Some stations were only focusing on CTD work and sampling from the Niskin bottles attached to the CTD, others just focused on helicopter stations and at some stations all operations took place (CTD, nets, ice-work, box-core).

For the CTD stations the CTD-rosette with the attached 22 Niskin bottles had to be prepared and also cleaned after each operation. For the sampling and measuring of the water samples some measurement instruments were standardized before and after each station to identify the drifting of the instrument. After the sampling water samples were directly analyzed with the help of different instruments, such as transient tracers with a gas chromatographic - electron capture detector system in connection with a purge and trap unit (GC-ECD/PT5) or oxygen using the Winkler method and others.

2.5.- TRACE

Infrastructure: IB Oden, SE

Type of access: TNA in person
Amount of access granted: 2,33 days
PI: Tim Stöven, GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

Number of onboard participants funded by ARICE: 1

Number of remote participants: 2

Scientific fields: Chemical Oceanography, Trace gases cycling. Sea Ice.

Geographic area: Central Arctic
Cruise dates: 25.07.2021 – 20.09.2021, Helsingborg, Sweden – Helsingborg, Sweden

Objectives:

Although the ocean is generally acknowledged as an overall source of these gases, at regional and basin-scales there is a large range of variability in terms of their sources and sinks, which in turn, poses challenges to the accurate assessment of their role in the marine nitrogen and carbon cycles. Environmental changes such as warming and decrease in sea ice coverage are expected to affect production/consumption pathways of both N2O and CO, but the direction of the future trends is highly uncertain.

Considering the large gaps of data coverage and process understanding with respect to the marine cycling of N2O in the Arctic marine ecosystem, the major goals of TRACE were to:

i) ascertain the magnitude and spatial variability of sea-air fluxes of N2O to the atmosphere over variable ice conditions in the central Arctic Ocean (CAO), and

ii) elucidate the major pathways involved in N2O production/consumption across the water column

TRACE aims to fill the gaps of both data coverage and process understanding with respect to the marine cycling of N2O and CO in the AO.

Short description of the work carried out:

Discrete sea water samples were collected from Niskin bottles on a CTD rosette with clean Tygon$^{®}$ tubing into 500 mL borosilicate bottles. Samples were overfilled with three times the bottle volume to eliminate air bubbles and poisoned with 200 µL of a saturated mercuric chloride solution. They were then transferred to a water bath at 25 ± 0.1 °C and temperature equilibrated for a minimum of one hour before analysis. Further discrete samples were also collected from the ships underway supply. Samples were analyzed for CH4 and N2O by single-phase equilibration gas chromatography using a flame ionization detector and Electron Capture detector similar to that described by Upstill-Goddard et al. (1996). Samples were typically analyzed within 12 hours of collection and calibrated with three reference gases calibrated against NOAA (National Oceanic and Atmospheric Administration)

primary standards. Samples were collected at selected stations identified below. Atmospheric concentrations were determined by the same methods using samples collected from the ships bow into a sealed Tedlar bag. All analytical procedures were carried out according to internationally recognized quality standards (Wilson et al., 2018).

During ice stations, young-ice cores were extracted and subsequently sliced in 15-cm sections, each of which was packed into a 2 L gas-tight bags which allowed the remaining air to be manually evacuated. Each sealed bag was then transported to the ship, where a saturated solution of mercuric chloride was added to preserve the sample and the air was evacuated. All slicing was performed on the ice. Once on board, ice samples were allowed to thaw under ambient temperature and upon full melting, resulting water was transferred to 500 mL glass bottles and analyzed on board. In order to measure N2O concentrations in waters directly beneath sea ice under undisturbed conditions, a rottener sampler was deployed below the bottom of the sea ice. The system consisted a sampling bottle open at each end, closed by sending a weight to close the sampler once the required depth was achieved. Samples were transferred to glass bottles and were treated/measured as explained above.

2.6.- ProMis

Infrastructure: IB Oden, SE

Type of access: TNA in person
Amount of access granted: 2,33 days
PI: Birthe Zaencker, The Marine Biological Association, United Kingdom

Number of onboard participants funded by ARICE: 2

Number of remote participants: 0

Scientific fields: Biological Oceanography.

Geographic area: Central Arctic
Cruise dates: 25.07.2021 – 20.09.2021, Helsingborg, Sweden – Helsingborg, Sweden

Objectives:

The Arctic summer sea ice extent and abundance of multi-year ice are decreasing (Kwok 2018). By the middle of this century, the Arctic will be mostly, if not completely, ice-free during the summer (Screen and Deser 2019). The loss of sea ice in the Arctic favours 'Arctic amplification' - the process of increased heat absorption by the newly exposed Arctic Ocean in a positive feedback loop (Serreze and Barry 2011). These physical changes in the Arctic Ocean are drastically impacting the biology and ecology of the region (Wassmann et al. 2011). However, the exact mechanisms through which the decreasing Arctic sea ice will influence the entire ecosystem are not yet clear, especially at the microbial scale. For example, higher stratification due to increased introduction of freshwater from the melting sea ice could reduce surface water mixing, making it more difficult for phytoplankton to utilise nutrients from deeper water layers. Higher light intensities due to loss of sea ice at the same time could increase photosynthesis rates and/or cause photo inhibition. This would greatly influence production of phytoplankton-derived organic matter (OM), which underpins the Arctic food web and biogeochemical cycles.

Phytoplankton are not only influenced by abiotic factors but also by microbial interactions. Up to 25% of a single diatom species (*Pleurosigma elongatum*) can be infected by fungi (Hassett et al. 2017), showing not only the importance of parasitic fungi for the overall diatom abundance, but also their importance in shaping the phytoplankton community structure via selective parasitism. Studies have shown that fungal infection rates are higher if the diatoms are stressed (Hassett and Gradinger 2016). Therefore, if diatoms are inhibited by light due to melting sea ice, fungal infection rates are likely to increase (Hassett et al. 2017). However, the specific impacts of Arctic sea ice loss on phytoplankton and their fungal parasites are difficult to predict because little is known about interactions and infection mechanisms.

Another factor influencing the export of phytoplankton-derived OM through the food web are saprotrophs that degrade biogenic particles. Part of the dissolved organic matter (DOM) pool excreted by phytoplankton are precursor compounds for the formation of Transparent Exopolymer Particles (TEP) (Passow et al. 2001), which are polysaccharide-rich biogenic gel-like particles that act as attachment sites and point sources of organic material for saprotrophic bacteria and fungi (Taylor and Cunliffe 2016; Cunliffe et al. 2017). Due to their stickiness, TEP also combine other particles in the water column and facilitate the formation of larger sinking particles (e.g. marine snow), which maintain the biological carbon pump (Passow et al. 2001). At present we have a limited understanding of how TEP production and processing will be impacted by sea ice state.

Mineral ballasting of organic matter also facilitates the biological carbon pump. One of the previously underestimated minerals in this process is cryogenic gypsum (Wollenburg et al. 2018), which has been observed to ballast a *Phaeocystis* under-ice bloom in the Arctic Ocean, increasing vertical carbon export (Wollenburg et al. 2018). Except for this single study, the influence of cryogenic gypsum on ballasting has not been fully evaluated but could potentially impact the carbon export in the Arctic Ocean significantly (Wollenburg et al. 2020). Most likely not only *Phaeocystis* and *Melosira* which have been previously associated with cryogenic gypsum (Wollenburg et al. 2018; Wollenburg et al. 2020), but also other microbes are associated with gypsum and are exported from surface waters to the deep ocean. Depending on the magnitude of this process, the export of microbes could alter the OM degradation in surface waters.

(1) We hypothesize that cryogenic gypsum increases TEP-related C-export in ice-covered sea compared to the open Arctic ocean.

(2) Fungi are abundant and active in the Central Arctic Ocean in the water column and the sea ice.

(3) Fungi control TEP production and concentrations not only by colonizing and consuming the carbohydrate-rich particles, but also by parasitizing phytoplankton, the main producers of TEP precursors.

Short description of the work carried out:

A total of 16 stations were sampled in total during the SAS21 cruise onboard IB Oden from 24th July to 21st September 2021. 10 of these stations were not only sampled for water but also for ice cores by the ProMis project with onboard participants Kim Bird and Birthe Zaencker. In order to look at the interactions of fungi and bacteria with phytoplankton and organic particles, almost 200 samples from different horizons in the sea ice and from water depths ranging from 5-3500 m were taken for microscopic analysis, bulk analysis, analysis of TEP- associated microbes, FISH and gypsum.

Samples to determine the weight and volume of gypsum in the ice were taken using ice cores and will be related to the abundance of phytoplankton, e.g. *Phaeocystis sp.,* and TEP. The water column was sampled using a net (30 µm pore size). To get a comprehensive picture of gypsum in the Arctic Ocean, the samples will be weighed, pictures will be taken and the mineral identification will be determined using Raman spectroscopy.

TEP abundance and area will be measured microscopically (Engel 2009). The sample volume (10-250 ml) was chosen according to the prevailing TEP concentrations determined under the microscope onboard. Samples were filtered onto 0.4 µm nucleopore membranes (Whatman) and stained with 1 ml Alcian Blue solution (0.2 g l^{-1} w/v) for 3 seconds.

Samples for sequencing (2 L) were filtered onto a Durapore membrane (Millipore, 47 mm, 0.2 µm) and immediately stored at -80°C. Any visible zooplankton were manually removed from the filters. DNA and RNA were co-extracted using the ZymoBIOMICS DNA/RNA Miniprep kits (Zymo Research). Beadbeating was carried out on the LLC FastPrep (MP Biomedicals). The extracted RNA was transcribed to cDNA using the SuperScript III Reverse Transcriptase (Invitrogen) according to the manufacturer’s protocol using random hexamers (Invitrogen) and the addition of RNAseOUT Recombinant Ribonuclease Inhibitor (Invitrogen).

For each sample, DNA and cDNA were sequenced to determine the total and active microbial communities respectively at the Northumbria University sequencing facility.

2.7.- PeCaBeau

Infrastructure: CCGS Amundsen, CA

Type of access: TNA in person
Amount of access granted: 10 days
PI: Lisa Bröder, Vrije Universiteit Amsterdam, NL

Number of onboard participants funded by ARICE: 9

Number of remote participants: 2

Scientific fields: Biogeochemistry.

Geographic area: Beaufort Sea, Canada
Cruise dates: 09.09.2021 – 07.10.2021, Resolute Bay, Canada – Cambridge Bay, Canada

Objectives:

The PeCaBeau project aims to track the movement and transformation of material from permafrost thaw along the land-to-ocean continuum. This multi-disciplinary effort investigates the sediment column between subsea permafrost and the seafloor, the water column, the atmosphere and the interfaces between these three units. By studying the sources, quantities and the quality of organic matter in the water column and in sediments, we aim to improve assessments of the Beaufort shelf as a carbon source or sink, and place these outcomes in the context of the Holocene paleoenvironment and transgressed permafrost.

The continental shelves of the Arctic Ocean are rapidly responding to global climate change. Rising air temperatures and declining summer sea-ice extent have direct consequences for the shelf environment. The ingression of warm water to the shelves impacts the coasts, which are more frequently eroded by fall storms during longer ice-free seasons, and accelerates subsea permafrost thaw. Furthermore, river runoff is warming and affecting associated particulate and dissolved matter fluxes, which are important for aquatic life in the nearshore zone. These changes in the Arctic may have profound ramifications for regional ecosystems and the broader Earth climate system because: a) increasing coastal erosion and shifting fluvial fluxes are releasing greater quantities of soil carbon and nitrogen to the nearshore zone that may be exported to the shelf and beyond, and b) warming and freshening of the water column is affecting the biogeochemistry of the shelf water, its interaction with the sea floor and air-sea gas exchange.

The overall goal of this project is to quantify the fluxes, burial rates, composition and fate of organic matter (OM) in the southern Beaufort Sea. We aim to differentiate between sources deriving from permafrost coastal erosion, Mackenzie River discharge and submarine permafrost degradation, and to investigate how these sources have changed in the Holocene. The major objectives are described below.

Objective 1: To better understand the role of the Beaufort/Mackenzie system in mitigating and/or facilitating carbon dynamics, we will characterize organic matter transformation from riverine and coastal sources to the water column and surface sediment during its transport from source to sink (sediment sampling, water column sampling, remote sensing).

To achieve this objective, 4 sub-goals are identified:

1.1 Quantification of the dissolved, particulate and sedimentary OM fluxes in the Beaufort/Mackenzie area.

1.2 Qualitative analysis of OM in the Beaufort/Mackenzie area using bulk and molecular geochemical methods.

1.3 Estimates of concentrations of dissolved and particulate organic carbon, and primary production

using satellite remote sensing data and collect in situ hyperspectral data.

1.4 Quantify lateral transport time on the Beaufort Shelf using compound-specific radiocarbon techniques on material collected along shelf-slope transects (as done on the Laptev Shelf by Bröder et al., 2018).

Objective 2: To evaluate whether modern sedimentation and carbon burial rates depart significantly from the long-term baseline. To do so we aim to recover paleoenvironmental sediment records to constrain past fluxes, and permit comparison of coastal and riverine sediment pathways over time. This will be achieved through gravity/piston coring for longer sedimentary sequences, and surface sediment sampling.

2.1 Quantification of carbon burial rates on the Beaufort Sea floor in space and time based on Pb/Cs, radiocarbon and paleomagnetic chronologies.

2.2 Development of paleo-oceanographic time-series documenting changes in the oceanographic and sea-ice conditions during the Holocene using micropaleontological, sedimentological and organic geochemical methods.

Short description of the work carried out:

Sampling operations took place in the Southern Beaufort Sea with five major across-shelf transects. Mapping surveys were conducted during the entire cruise, radiometry measurements were performed under way and at 18 locations, water-column profiling and sediment sampling were conducted at 35 and 27 stations, respectively.

The offshore science party joined the CCGS Amundsen on September 9, 2021, with the departure of the vessel from Resolute Bay on the following morning. During the first days of transit, the research team engaged in general safety training and specific toolbox meetings regarding the deployment of the different coring devices (Multicorer, Gravity Corer, Piston Corer, Box Corer), unpacked and set up equipment in the sediment and filtration laboratories, assembled the Multi Sensor Core Logger (MSCL) and the Multicorer. The Multicorer was then deployed for a first succesful test in the Amundsen Gulf on September 16. At station C014, a first test of the radiometry system was performed. On October 7, 2021, cruise participants disembarked in Cambridge Bay.

2.8.- Vessel operator experience

In order to find out the experience of the ship operators in the implementation of the TNA proposals, a survey was carried out, very similar to the one carried out in D4.8, but in this case aimed at the vessel operators (Appendix 1). Their responses to the sections of the survey have been very positive and the relationship with the project participants, especially with the PIs, was always good and collaborative.

The first group of questions was about the relationship with the project in the preparation phase of the cruise, equipment, documentation and logistics. For all the operators, the information in the proposal was good enough for the aspects that have to do with the preparation of the campaign, both from the operational point of view (logistics, personnel needs) and from the point of view of the necessary documentation. The communication with the PI was fluid and good at all times.

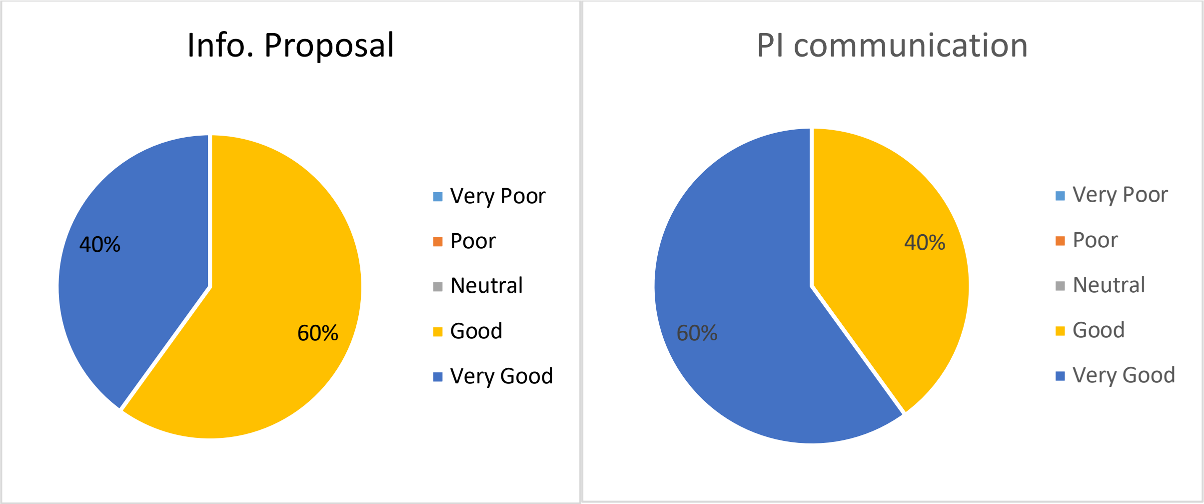

Fig. 1 & 2 Statistics about information from the proposal and communication with the PI

The other aspects of the preparation of the campaign were valued by the operators as very good in 100% of the cases. The most complicated aspect in the preparation of the TNA proposals was undoubtedly the requirements imposed by COVID-19 pandemic that made the initial logistics more complicated, requiring researchers to quarantine at the ports of departure. All the operators highlighted that both the objectives of the proposals and their integration into the ships' schedules were relatively easy, being able to accommodate the necessary equipment and the researchers on board.

When asked about how the project was implemented on board, all the operators highlighted the excellent relationship that was created between the different projects that were on board at the same time. Some operators indicated that the normal way of working on their vessels is to have different projects coexisting on board, which facilitated the integration of ARICE's proposals.

In general, all the operators conclude that the integration of the proposals was a success and that there were no major problems.

3. Cruise Summary Report (CSR)

Cruise Summary Reports (CSRs) are the usual means for reporting on cruises or field experiments at sea. They provide metadata for scientists, data managers and programme managers to find information on who has collected what, when and where. It is the Chief Scientis's or PI obligation to submit to the ARICE project a CSR no later than 2/3 weeks after the cruise. CSRs have to be submitted to the vessel's National Oceanographic Data Center as part of the cruise metadata.

CSRs provide an initial record for the cruise, including different aspects like data and samples collected and other cruise metadata, it consists of 8 parts in which the PIs of the projects have to summarize what happened during the campaign in different aspects. An online tool "CSR back-office" allows chief scientists to create and update CSR entries by submitting CSR XML files to SeaDataNet in CSR format or by completing an online form.

As described on D7.8. "Report on performances and use of the ARICE system and compliance with standards" in point 4.3. within the ARICE project, a specific polar CSR inventory was implemented, using the SeaDataNet CSR database, standards and interface. The polar inventory contains a subset of the SeaDataNet global inventory which has been extracted based on geographical criteria (namely polar and subpolar ocean areas) (see https://arice-h2020.eu/data-tools/)

4. Lessons Learned

The implementation of ARICE's TNA projects has resulted complicated in many aspects. First, the integration of international projects in national schedules has not been trivial. Funding systems of polar programmes are very different from nation to nation and the negotiation and implementation has not always been straightforward. Despite of this, multinational, multidisciplinary and collaborative cruises have been implemented, demonstrating that international cooperation is an effective tool in breaking (among others) administrative barriers.

Second, transnational access opportunities are very often benefiting Early Career Researchers (ECRs). They provide a way of accessing a different pool of infrastructures from their national programmes and innovative tools and methods are often deployed and/or applied. This results in a challenge for the vessel operators and technicians on board. In ARICE, 45% of the researchers boarding the vessels were ECRs.

A series of lessons learned during the preparation and development of the campaigns are summarized below:

1.- COVID-19 Pandemic. The impact of the COVID-19 pandemic has been important in the development of the implementation of TNA's proposals. During the first part of 2020, research activity on ships was stopped, significantly impacting the scheduled programs of research vessels. The delay generated by confinement and the impossibility of traveling meant an even greater delay in the implementation of TNA's proposals.

In addition to this, the different measures and requirements adopted by different countries made the initial logistics of the campaigns complicated, taking into account that the ARICE polar ships belong to 6 different countries.

Therefore, in addition to the delays, there were new measures that operators and researchers had never had to go through such as special medical reviews, pre-embarking quarantines, cargo disinfection, etc.

All these new measures are going to remain active for a time, so it is very likely that medical restrictions will be maintained in the future, not specifically for COVID-19, but surely medical issues will be monitored. Therefore, both operators and researchers will need to be prepared to have to perform some medical examinations, especially those working in high latitudes such as the Arctic.

In this sense, it will be necessary to work on the harmonization of this type of requirements to facilitate the exchange of researchers between infrastructures in different countries. An example of this could be the medical examinations required for participation in Antarctic expeditions that are agreed within the COMANP (Council of Managers of National Antarctic Programs) and that are standard for all the signatory countries of the Antarctic Treaty, facilitating the access of researchers with medical examinations carried out in their own countries.

2.- Advancing planning. As previously mentioned, polar research vessels are infrastructures that are in high demand and expensive to operate, especially those that are icebreakers. The planning of the calendar of these ships is done in most cases with 16 to 18 months in advance, so it is necessary to know with the same advanced time the proposals that must be implemented. This is important in order to accommodate the TNA days on the vessels since the requirements of the projects that are already on board are known quite in advance. The maximum anticipation for logistics is quite important, especially for projects to be carried out on Canadian or American vessels, shipping times have increased and risen in price considerably in recent years due to the COVID-19 pandemic and the increase in the fuel prices, which will surely continue in the near future.

3.- Estimated daily rate costs. In the application of the costs related to the implementation of the TNAs, it is important to be clear from the beginning about the associated costs per day. For project management, the correct sizing of costs is vital for efficient budget management. And for the ship operators as well, since it would avoid costs associated with the implementation of the TNAs that have to coexist with other projects on board. Another important aspect in terms of planning is that in the polar areas the home ports of the vessels are generally a long way from the working areas, which means long cruises. This, due to the high price of fuels, could reduce the ability of the operators to accept TNA proposals in the future. For research cruises hosting different research groups simultaneously, a berth fee (cost per person per day) seems a better approach to calculate the unit cost than the full cost of one day of ship time.

In this sense, perhaps in future projects in which TNA is implemented, it is necessary for the operators to calculate the cost per day, taking into account all the aspects that affect this calculation in its normal operation. As previous mentioned in point 2, the possibility of scheduling well in advance will allow a better management of the TNA implementation.

4.- Science Synergies. One of the aspects most widely expressed both by the Principal Investigators and by the vessel operators, is the joint implementation of several projects on different topics simultaneously. This has allowed researchers to interact with other researchers in other disciplines, generating synergies between them leading to new research or collaborations. This is a key point in the implementation of long cruises since it enriches the initial objectives of the proposals by adding new scientific values. Especially for young researchers, this modality can be a way to create contact networks and open new research perspectives.

5.- Data management. In order to justify the project and the public availability of the data obtained, it is mandatory that the operators know and apply the data management system created within ARICE, in addition to complying with the national requirements in this aspect. However, the management of the metadata and CSRs has not always been initiated on board. This must be a practice that operators and researchers must be aware of and must be enforced.

Appendix 1

1.- General Questions

1. Name of the cruise proposals you allocated:

2.- Cruise Preparation

Please, value from 1 to 5, where:

1.Poor; 2.Fair; 3.Good; 4.Very good; 5. Excellent

2. Was the information about the proposal and the equipment from the science team clear enough to prepare your cruise?
   Value:
   Comment:

3. Contact with vessel PI was easily established? With the rest of the scientific team?
   Value:
   Comment:

4. The information about the proposal was enough to prepare vessel logistics?
   Value:
   Comment:

5. Information required for the cruise preparation, diplomatic clearance, specific trainings or health insurance issues was clearly communicated and provided in time?
   Value:
   Comment:

6. How difficult was the implementation of the cruise in your planning? (equipment and vessel capability, cruise dates, shipment dates, cruise logistics, …)
   Value:
   Comment:

7. Was the information from the PI sufficient to judge interoperability of own and marine equipment?
   Value:
   Comment:

8. Specific regulations needed for COVID and health and safety were answered clearly and timely by the PI and scientific team?.
   Value:

Comment:

9. Generally, how was your relationship with the scientific team during pre-cruise activities (planning, coordination and logistics)?
   Value:
   Comment:

3.- Cruise Performance

10. Did you lose science days by: Weather, ship’s equipment problems, other?
    Y/N:
    Comment:

11. Were there changes in the on board team compared to the proposal?
    Y/N:
    Comment:

12. Were the offered days at sea sufficient?
    Y/N:
    Comment:

13. How was your experience as operator having ship time sharing with different science groups?
    Value:
    Comment:

3.- Data Management Plan (DMP)

14. Did PI prepare prepare the Cruise Summary Report in time?
    Y/N:
    Comment

15. Was the CSR available to prepare on board?

3.- Summary

16. Was the scientific cruise successful overall/work programme completed, according to the proposal?
    Value:
    Comment:

17. Were the science objectives planned achieved?

Value:
Comment:

18. How was your general experience having TNA on your ship? (life on board, accommodation, food,…)
    Value:
    Comment:

4.- Lessons learned.

Please, could you finally add lessons learned of the implementation of TNA cruises in your vessel. In general what was ok what not…