8 OVERARCHING AND SUPPORTING ACTIVITIES

Grant-No. AWI_PS122_00

8.1 LOGISTIC & SAFETY

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Objectives

The main objective was the overall safe conduction of the expedition.

For MOSAiC a specific safety concept based on the AWI safety standards as well as project specific needs and experiences from previous drift expeditions had been developed by B. König and V. Mohaupt.

Work at sea

A safety briefing, including specific information about MOSAiC as well as general field safety and polar bear safety and awareness was mandatory for all participants before departure in Bremerhaven, to ensure a good level of general safety awareness and knowledge.

Due to Covid-19 restrictions and quarantine regulations practical parts such as self-rescue from sea ice and the use of emergency equipment was carried out during transit.

After arrival at the new ice floe, conditions of the floe needed to be assessed, feasibility of rules and regulations needed to be verified. If required, the safety concept was adapted to match conditions. Expedition participants were informed directly as well as via corrections to the MOSAiC handbook. The science team was a consulted body during this process.

Current check of work safety standards was carried out by V. Mohaupt. Necessary measures were taken if required and participants were briefed accordingly.

The logistic team in general was the controlling body for the predefined safety rules and standards during the expedition. The main tasks were carrying out bridge watch, stern watch and polar bear watches on the ice. Further duties were the management of infrastructure and the distribution and maintenance of safety equipment including rifles and flare guns for polar bear protection.

The logistic team was also responsible for vehicles and vehicle maintenance (snow scooter, ARGO). An introduction regarding safe use of snow scooters and basic technical knowledge was required for all participants.

Mandatory refresh courses for weapon handling were held on site for all potential polar bear guards among participating scientists. Proper weapon handling was checked throughout the expedition. Regular maintenance of weapons and weapon equipment was carried out.

The bridge watch was in charge of coordination and monitoring of the teams on the ice. In case of events (cracks, fog, bad weather, polar bears, breaks ups) the logistic bridge watch was managing and advising the teams and inform and consult the cruise leader if needed. All actions were carried out in cooperation with the nautical officer on watch.

In case of polar bear encounters members of the logistic team – in consultation with the Cruiseleader – took measures to scare the animal(s) away.

According to the developed emergency concept, a member of the logistic team, together with the officer on watch would be in charge of a potential medical evacuation.

An exercise of a medical evacuation situation was carried out to assess the concept in terms of flaws and allow optimization in close contact with the ship's management.

Organisation and management of freight and cargo issues was undertaken in close cooperation with the ship's management by V. Mohaupt.

The logistic team assisted during the re-build-up of the central observatory as well as in the final evacuation at the end of the expedition. The team also assisted in field trips and logistic operations (retrieval or moving of equipment) and took responsibility in maintenance of infrastructure (power lines, roads, shelters, ice holes, bridges).

Preliminary (expected) results

Not applicable

Data management

Not applicable

References

Not applicable

Special requirements on notations:

Not applicable

Images

Not applicable

8.2 DATA SUPPORT

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Not on Board[1]: Janik Eilers, Peter Gerchow, Antonia Immerz, Sebastian Immoor, Roland Koppe, Jörg Matthes, Martin Petri, Stefan Pinkernell, Jens-Michael Schlüter, Andreas Thiele.

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Objectives

General accessibility of data requires a central data storage and a common meta data concept. All sensors and sampling devices used in scientific events during the MOSAiC expedition shall therefore be registered in SENSORWeb and all device operations performed during the expedition logged in the ships station book, the DSHIP ActionLog. A predefined structure on the MOSAiC central storage further ensures that data can be found in an organised manner, also after the expedition. In this way all subsequent sample analyses can then be referenced to the original sampling event. A full description of the data management concept in MOSAiC can be found in the MOSAiC Data Policy (see Appendix).

Work at sea

For general tasks, see Work at Sea, all previous legs.

Network Infrastructure:

After arriving at the floe on Friday, August 21st, parallel to the reconnaissance of the floe, the first instruments were installed on the ice and started to record data.

The initial camp buildup began the next day. Alongside with the general installations, the power cables were laid to the approximate locations of the planed main sites. On day 4 a small crack widened and cutoff the logistic area from the rest of the camp, the ship was moved forward and the cables had to be reorganized. Once power was available Remote Sensing and Met City were provided with the existing RadioLan setup developed during Leg 4. For Ocean City fiber optic cables were rolled out to provide a reliable connection for the online recording of the ADCP. These connections worked very well throughout the whole leg. The RadioLan installation did not need any maintenance, the fiber optic cable only needed to be pulled out of the snow once in a while. All systems reconnected properly after power shutdowns due to polar bear visits in the camp.

Assistance was provided to scientists connecting their instruments to the network, both within the vessel and on the main sites.

Satellite Communications:

The Iridium Network performed well during Leg 5 except close to the pole due to changes in the configuration of the setup and minor outages every day, which may be related to handover of the satellites.

During Leg 5 data was also transferred regularly via the Kepler satellites. This worked reliably within the limitations of the system. Therefore, Kepler was used frequently and mainly to send troubleshooting reports to land and get back precious help how to maintain instruments which did not work properly. The system was further used for the transfer of scientific data as preliminary results to colleagues on land, media files and other purposes. In total we uploaded 7.8 Gigabytes and downloaded 5.4 Gigabytes via Kepler system on Leg PS122/5. On the transit form Svalbard to Bremerhaven the main antenna was switched from the Kepler system to the leased line via geostationary satellites by the ships communication officer.

Unfortunately, no connection could be established due to unidentified problems, therefore the finalizing of the Leg 5 and overall MOSAiC data operations had to be done via the slow Iridum network.

Data Management:

Besides trainings and assistance in using the provided infrastructure with all its components including fileserver, virtual machines, the sensor registry SENSORWeb and the DSHIP

ActionLog. Correct logging of device operations when entering and exiting the 12-mile zone was communicated.

The latest FloeNavi-App (v3.2.1) was installed on multiple tablets for a broader in-field test. The logistical installations were situated on the freshly created local grid. This worked well after applying a patch (v2.2.1) that fixed some synchronisation problems with the server-side counterpart.

Tasks covered by the data support team included the batch-wise registration of event relations in SENSORWeb based on lists provided by the scientists. Event relations were created for lab analysis data to document with which laboratory instruments field samples had processed or analysed. Event relations were also created for secondary instruments co-deployed in the field together with main sampling or measurement devices which themselves are logged in DSHIP.

Cleanup- and checks brought many missing Event-Relations – even back to Leg 1 – to light. This took serious effort both from the scientists and the data team to reconstruct what was done in the previous legs.

Preliminary results

An expedition leg is subdivided into so-called Science Activities in DSHIP, which in turn are composed of numerous device operations. In MOSAiC the weekly schedule for scientific work is represented by weekly incrementing Science Activities. For leg PS122/5 the following Science Activities were defined:

- Science Activity 0: Continuously measuring instruments always running on *Polarstern* (e.g. Ferrybox, Thermosalinograph, etc.) and therefore normally logged by the system administrator.
- Science Activity 58: All continuous measurements or sampling instruments that are deployed on *Polarstern* or the ice for MOSAiC (i.e. buoys, radars, sediment traps amongst others)
- Science Activity 59: Discrete sampling or short-term measurement events performed during the transit and the buildup of the camp.
- Science Activity 60 - 62: Discrete sampling or short-term measurement events performed within the scope of the weekly scientific schedule starting with Science Activity 60 on August 31th 2020. Generally, a new Science Activity starts at 00:00 UTC every Monday.
- Science Activity 63: This Science Activity started with our departure from the flow at 13:00 UTC on September 20th 2020. And contains all discrete sampling or short-term measurement events performed during the transit phase from the floe to Bremerhaven except during our sojourning in the territorial waters of Svalbard from October 2nd 4:00 UTC till October 4th 17:00 UTC. This last Science Activity of leg PS122/5 ended on October 12th 2020 with the arrival at Bremerhaven which marks also the end of the MOSAiC expedition.

A total of 1812 Device Operations comprising one or more Actions were logged during leg PS122/5.

Altogether, approximately 20 Terabytes of data, including 110 thousand directories and 746 thousand files, were uploaded to the MOSAiC Central Storage on *Polarstern*.

8.3 MELT PONDS (CROSS CUTTING)

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8.1.1 Objectives

To understand variability and development in physical, chemical, and biological properties in melt ponds during the open water and freezing period, and to study the interactions between the pond water, ocean, ice, and atmosphere.

8.1.2 Work at melt ponds

The main process we aimed to capture was the onset of autumn freezing at the end of the summer season. The initial idea for the melt pond study was to sample a set of chosen melt ponds at least weekly to track changes over time. However, many rapid changes occurred at much smaller time scales, such as freezing and melting, wind events, snow events, etc. In order to be able to constrain the impact of these processes on the melt ponds, the sampling frequency was increased. The sampling was driven by opportunistic availability of resources and time. This resulted in some time points being sampled by multiple or single teams; i.e. not all parameters were always sampled/measured at the same time points.

On initial arrival at the Leg 5 floe on the 22nd August 2020, a survey was undertaken of 12 different melt ponds (Figure 8.1.1, Table 8.1.1) to examine the opportunities for ice and water sampling for each team (and thus various parameters). Figure 8.1.1a shows the spatial distribution of the chosen melt ponds on the starboard side of the vessel on 22/08/2020. These melt ponds were chosen based on accessibility, restrictions imposed by other study sites on the floe area that could not be disturbed for other measurements, and including a variety of shapes and features of different melt ponds (Table 8.1.1). Variability in melt ponds included their shape (round, elongated), their depth (30 cm to > 100 cm), their connectedness to the sea water below, their connectedness to other melt ponds, and visible biomass. Note that some sites that were labeled as “melt pond” at the beginning and received a melt pond number were actually cracks that connected some of the melt ponds. These cracks (labelled, and often referred to, as “melt pond” sites throughout the study period) are numbered as station number 3 and 8. In this chapter (and in Chapter 8.2, we also refer to them as melt pond stations 3 and 8. On 24/08/2020, a lead opened up through our floe and melt pond study site (Figure 8.1.1b and c). This resulted in a significant number of previously selected melt ponds becoming inaccessible (specifically, melt ponds numbered 9, 10, 11, and 12) or lost as part of the lead (specifically, melt ponds numbered 2, 3, and 8). After the opening of the lead (most often referred to as the “Remote Sensing lead”, and occasionally as the “Seismic lead”, especially in Chapter 8.2), only melt pond sites 1, 2, 3, 4, 5, 6, 7, and 8 continued to be accessible. However, due to significant time and resource limitations, the decision was made to focus on

only two melt ponds: sites 1 and 4. Sites 3 and 8 were continually sampled as part of the lead sampling project (Chapter 8.2). Melt ponds 1 and 4 were chosen because of their contrasting characteristics. Melt pond (MP) 1 was small, round and approximately 4.5 m x 4.5 m and 40 cm deep, a pale blue color with no dark patches. In contrast, MP 4 was much larger and deeper (25 m x 15 m and irregular shape), with a layered bottom profile and connections to open water through surface channels, as evidenced by the presence of live biota.

The datasets thus show some variation in terms of time points, parameters and melt pond locations.

A few highlights related to melt pond work during PS122/5:

- Team BGC led a melt pond mixing experiment on 02/09/2020.
- A temperature profile was continuously measured during PS122/5 for melt pond 1.
- Team BGC performed stable isotope melt experiments on ice samples collected from melt ponds. See Section 7.2 of the cruise report.
- Comparison of gas chamber and flux measurements between Teams BGC and ATMO. See Table 8.1.4. and Sections 7.2 and 3.5 of the cruise report.
- Particle chamber experiments were performed on water collected from melt ponds by Manuel Dall'Osto. See Chapter 7.5 .

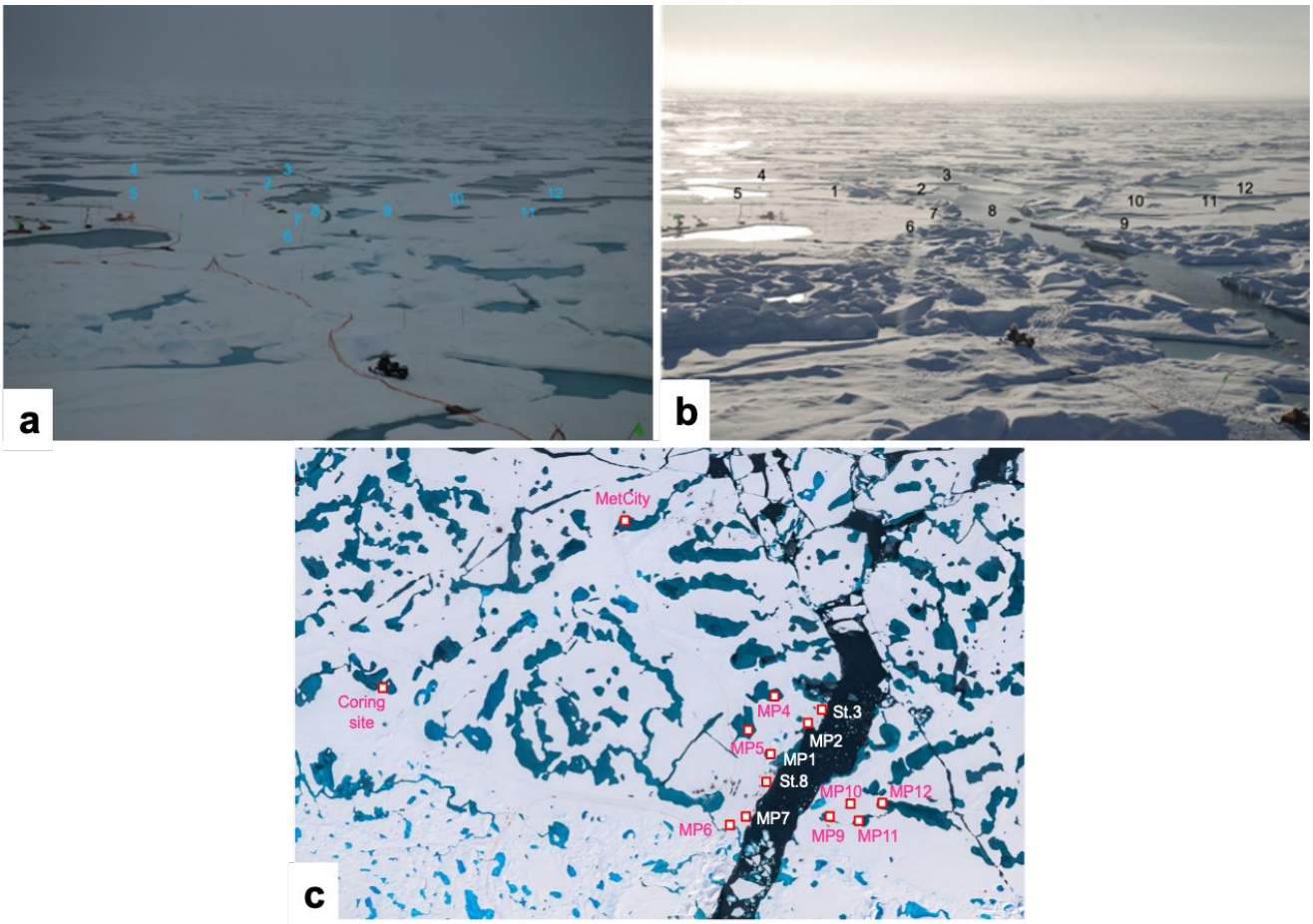
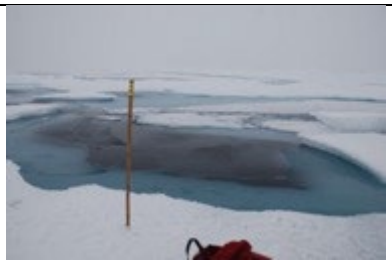


Figure 8.1.1. a) Location of the different melt ponds as seen from the vessel (starboard side). Photo taken on 22/08/2020. b) Photo taken from the vessel on 24/08/2020 featuring a lead that formed through the floe and melt pond study area. This made melt ponds numbered 9, 10, 11, and 12 inaccessible for sampling. "Melt ponds" numbered 2, 3, and 8 became part of the lead. c) Aerial photograph of the melt pond study site on the PS122/5 floe, captured on 25/08/2020.

Table 8.1.1. Brief description, photo, and field notes on each melt pond surveyed on 22/08/2020. Notes are those made during the initial survey on 22/08/2020.

Melt Pond No. (assigned on 22/08/2020)	Photos taken of the melt pond on 22/08/2020	Description/Notes
1		○ Closed i.e. closed at the bottom ○ Light blue colour ○ Covered by a layer of ice on top
2		○ Seems to be melted through at the bottom (later shown NOT to be the case i.e. false bottom) ○ Mostly covered by ice at the top
3		○ This was not really a melt pond, but more of a connection between melt ponds; a crack ○ Had a small stream/current ○ Partially frozen ○ Open at the bottom
4		○ Frozen over ○ Gaps/holes in the bottom; connected to underlying seawater
5		○ Frozen layer on top ○ Closed at the bottom, except: ○ There is a crack at the bottom through the middle of the pond
6		○ Elongated shape ○ Closed at the bottom ○ Frozen over

7		○ Frozen over ○ Closed at the bottom
8		○ This was actually more of a connection between ponds rather than a melt pond; a crack ○ Open to ocean below ○ Here we did a mini profile on 22/08/2020; we sampled at the surface (0 m) and at 2 m and 4 m depth
9		○ No notes made on 22/08/2020, but pond was closed at bottom and was connected to melt ponds number 11 and 12
10		○ This was a small, closed pond ○ Light blue colour ○ Melt water on top of the refrozen surface ○ Closed at the bottom
11		○ Linked to many other melt ponds (melt ponds number 9 and 12) ○ Thin layer of ice on the top ○ Partly open at the bottom, but patchy ○ Connected to melt pond 9
12		○ Quite a large pond! ○ Wind creates little waves, which seems to make it harder for ice to form at the top. ○ Not completely frozen over, but frozen over at the location of sampling ○ Closed at the bottom where we sampled and seemingly also everywhere else (from what we could see). ○ Connected to melt pond number 11

Sampled and measured parameters

On each melt pond sampling occasion, assessments were made of surface ice thickness, surface ice temperature, melt pond width and depth. Although 12 melt pond stations were surveyed initially, loss of the stations due to ice dynamics meant that melt ponds 1 and 4 were studied most extensively throughout leg 5.

Temperature sensors (TR52i, T and D) were installed by Team BGC in melt pond (MP) 1 on 28th August 2020, prior to onset of autumn freeze up. These monitored the temperature throughout the surface profile of the melt pond (1.5, 5, 10, and 20 cm depth), and gave a time series to which the discrete sampling could be compared.

Teams BGC and ECO collected both water and ice samples from the melt ponds for a number of different parameters. Water from melt ponds and leads was collected in a gas tight manner using a peristatic pump (Master flex E/S portable sampler) from the surface 0.1 m down to 2 m (generally, 3–4 layers) and subsampled into gas-tight bottles for each parameter (Table 8.1.2). Large water volumes for HPLC, DNA and Chl-a were collected using a portable hand pump as these samples did not require gas tight conditions. The portable CTD (ASTD103, JFE Rinko profiler) was used to measure vertical temperature, salinity, and dissolved oxygen (DO) concentration within the melt ponds. In addition, CO_2 equilibrated air-in-water was measured *in situ* with the CO_2 analyzer (LI8100A, LI-COR).

For the gas-tight water samples, the BGC parameters were:

- pCO_2
- DMS, DMSP, DMSO
- N_2O
- CH_4
- $\delta^{18}O$

The standard non gas-tight ECO parameters were:

- Dissolved inorganic carbon (DIC) and total alkalinity (TA)
- chlorophyll a
- nutrients
- DNA
- POC
- PON
- HPLC
- PAM

Table 8.1.2. Water sampling dates and device operation IDs in various melt ponds by Teams BGC and ECO. Note that samples for gases were *usually* collected with the peristaltic pump and non-gas sensitive samples with the hand pump. The CO_2 equilibrator is occasionally listed as the device operation ID, in which a peristaltic pump was used to collect the sample.

Date	Location	Device operation ID
22 Aug. 2020	MP 1 to 12	PS122/5_59-200, 202, 203, 207-215 (peristaltic_pump)
23 Aug. 2020	MP 1 to 12	PS122/5_59-223-234 (RINKO-pro_592)
24 Aug. 2020	MP 3, 4, 8	PS122/5_59-258 (MP 3), PS122/5_59-259 (MP4), PS122/5_59-260 (MP 8) (RINKO-pro_592)

25 Aug. 2020	MP 8, 3	PS122/5_59-297-298 (MP8), PS122/5_59-297-417 (MP3) (RINKO-pro_592)
28 Aug. 2020	MP 1 and 4	PS122/5_99-6-7 (RINKO-pro_592), PS122/5_59-343, 59-344 (CO2-equilibrator-sea-ice)
29 Aug. 2020	MP 8	PS122/5_59-419-420 (RINKO-pro_592)
1 Sep. 2020	MP 4	PS122/5_99-16-17 (RINKO-pro_592), PS122/5_60-23 (hand_pump)
2 Sep. 2020	MP 4a	PS122/5_00-20 (RINKO-pro_592), PS122/5_60-61 (peristaltic_pump)
9 Sep. 2020	St. pond river 1-12	PS122/5_61-126 (RINKO-pro_592), PS122/5_61-127 (hand_pump)
12 Sep. 2020	MP 4b (mixing experiment)	PS122/5_61-207 (RINKO-pro_592), PS122/5_61-205 (peristaltic_pump)
14 Sep. 2020	MP 4a	PS122/5_62-34 (RINKO-pro_592), PS122/5_62-33 (peristaltic_pump)
15 Sep. 2020	MP 8	PS122/5_62-41 (RINKO-pro_592), PS122/5_62-40 (peristaltic_pump)
17 Sep. 2020	MP 1	PS122/5_62-117 (RINKO-pro_592), PS122/5_62-116 (peristaltic_pump)

In addition, at stations 3 and 8 when water did not need to be conserved, additional ECO samples were collected for: O_2/Ar, bacterial production, NPP, flow cytometry, light microscopy, cDOM, and DOC. More information for stations 3 and 8 can be found in the chapter on lead work (Chapter 8.2).

Complementary to the water sample collection, surface ice on the melt ponds was measured for thickness and surface temperature, prior to collection of surface ice blocks/cores using an ice saw/ice corer on multiple occasions across the duration of Leg 5 (Table 8.1.3). Ice samples for DIC/TA, CH_4, $\delta^{18}O$, and N_2O analysis were collected and melted in gas-tight bags at +4°C, in the dark. Additionally, a number of experiments were carried out on a separate set of ice samples where the ice was melted in saltwater equivalent to the under-ice salinity, at 4 °C and low light conditions. Stable isotopes were added in known concentrations to study the turnover of sulfur compounds (DMS/P/O) during the melt process (see Chapter 7.2). Following the melt, the following parameters were analysed from these experimental bags:

- DMS, DMSP, DMSO
- HPLC
- PAM
- Chlorophyll a
- Nutrients
- DNA
- POC
- Salinity
- Temperature

Table 8.1.3. Ice sampling in the melt pond by Teams BGC and ECO.

Date	Location	Device operation ID
22 Aug. 2020	St.MP1-12 pond ice (block)	PS122/5_59-433 – PS122/5_59-441
28 Aug 2020	St MP1 surface ice block	PS122/5_59-445
28 Aug 2020	MP 4 surface ice block	PS122/5_59-444

7 Sep. 2020	MP 4a	PS122/5_61-6 (this is a dship number for the ice cores at the coring site, not the ice cored at the melt pond. New dship number tbd)
12 Sep. 2020	MP 4b pond ice (core and block)	PS122/5_61-206
14 Sep. 2020	MP 4a pond ice (core)	PS122/5_62-35
18 Sep. 2020	MP 1 pond ice (core)	PS122/5_62-120

On three occasions during Leg 5 (31st August, 2nd September, 24th September 2020), Teams BGC and ATMO simultaneously examined the gas flux measurements (Table 8.1.4):

- Team BGC: automatic open/closed chamber system for CO_2/CH_4 (915-0011, Los Gatos Research/LI8100A, LI-COR)
- Team ATMO: dynamic chamber for CO_2/DMS (see Chapter 3.5 for more detail)
- Team BGC: Teflon-coated metal chamber for N_2O/CO/DMS/CO_2/CH_4

More details can be found in each respective Team's cruise report chapter.

Spectral albedo was measured by Team ICE on one occasion at MP 4 and MP 5 using an ASD FieldSpec3 spectroradiometer (device: dart_asd). Three sets (incoming and reflected radiation) were collected at each pond site, as well as from a nearby crack. Additionally, a stickle set up was used to collect five spectra for each spectrometer at each site, measuring spectral albedo and remote sensing reflectance (device: cau_stickle_1). A notecam collected photos and GPS coordinates (see photos in Figure 8.1.8). An action cam AC1 was mounted on the stickle, looking downwards.

8.1.3 Preliminary (expected) results

Observations

General observations (Team ECO & Team BGC)

Of the 12 melt ponds initially included in the investigation, depth ranged from 40 to 100 cm, with different water colours depending on the thickness of the ice underneath the ponds and amount of biological activity. It was noted that often when melt ponds had a dark colour at the bottom and seemed to have been melted through (meaning direct connection with the sea water below), this was often not the case and instead the melt ponds had "false bottoms" consisting of a very transparent layer of ice at the bottom. We found significant quantities of floating organic material within some melt pond water, especially MP 4, along with significant further organic material settled at the bottom of the pond and frozen into the bottom ice (Figure 8.1.2). Green/brown material was mainly composed of the chain forming diatom *Melosira,* while the white material comprised re-mineralized organic matter following degradation, including the remains of krill and other zooplankton (observed by K. Schmidt, Team ECO).

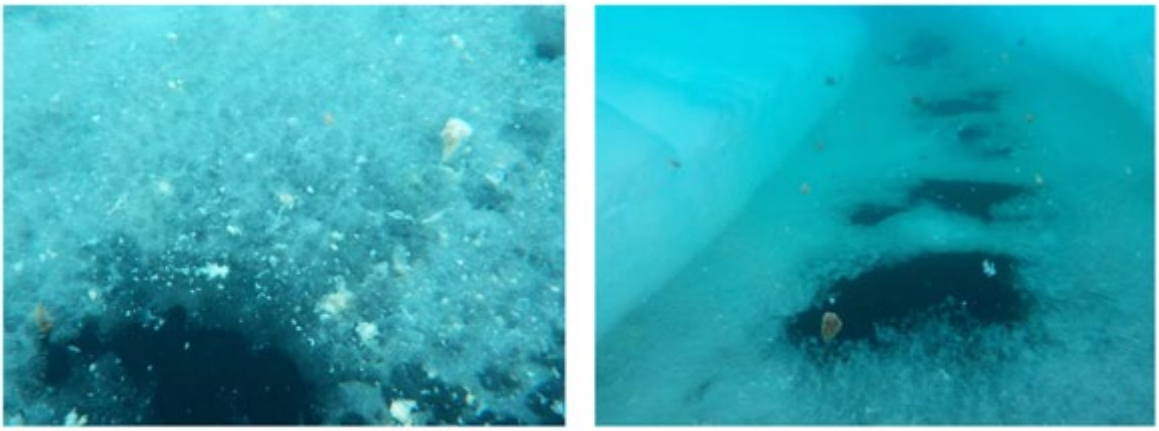


Figure 8.1.2. Pictures of the organic layer at the bottom of the melt pond (left) (MP 4a) and floating materials within the melt pond (right) near MP 4 (30 August 2020).

Some observations made on the ice:

- 24/08/2020: Big lead opened up through the floe and melt pond study site (starboard).
- 24/08/2020: Sunny day, ice on top of melt ponds melted a bit.
- 25/08/2020: Lead that opened up on 24/08/2020 has become narrower and is almost completely frozen over.
- 28/08/2020: Observation of complicated bottom of melt pond 4. Lead has narrowed even more. Ice that had formed on top is being compressed.
- 01/09/2020: Relatively warm day. Top of the ice is melting and most ponds are open at the top again (melted). Dynamic sea ice. Lead at melt pond location looks much narrower.
- 15/09/2020: A bit of snowfall.

Characteristics of the inside the melt pond (Team BGC & Team ECO)

Figure 8.1.3 shows the temporal variation in temperature within the melt pond (MP 1). At the beginning of the ice floe work during Leg 5 (22 September 2020), temperature in the melt pond decreased from around zero to –1.5°C. This decrease in temperature corresponded a decrease of the atmospheric temperature and showed the initiation of the freezing period. At the end of the ice floe work during Leg 5 (18 September 2020), thickness of the pond surface ice was about 19 cm, compared to 1–3 cm during the initial melt pond survey.

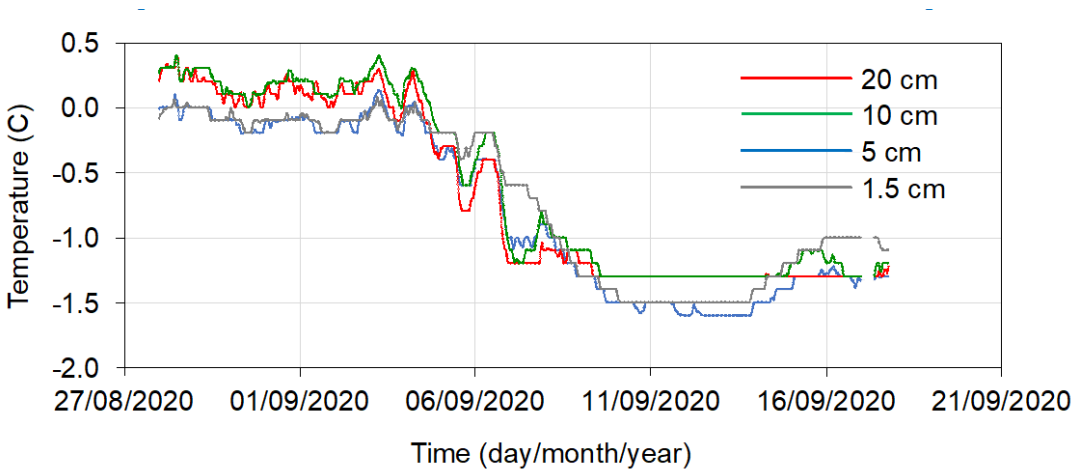


Figure 8.1.3. Time series of the temporal of the melt pond surface at MP 1.

Vertical profiles of temperature, salinity, and DO in the melt pond (Team BGC)

Figure 8.1.4 shows the vertical profiles of temperature, salinity, and dissolved oxygen (DO) in the melt pond (1st September 2020, MP 4a). There were strong vertical gradients from the surface to the bottom of the melt pond (within 1 m depth): from +0.2°C to –1.5°C for temperature, from 0 to 29 psu for salinity, and 9.2 to 13.5 mg L^{-1} for DO. This strong salinity gradient was identified in both melt ponds and the surrounding leads, and the stratification was a clear limitation on gas and material exchange with the surface, as seen from the concentrations of DO. The DO minimum layer (below 9 mg L^{-1}) corresponded with a salinity of 25 psu, and increase to over 13 mg L^{-1} at the atmospheric interface. At the end of Leg 5 (Mid-September 2020), these strong gradients had disappeared, likely due to the mixing events during the cooling and freezing periods. A very similar pattern of these characteristics was observed at the lead site (e.g., sites 3 and 8). In the future, we will analyze the CTD data and examine the temporal variations of the melt pond and lead water properties, including the biogeochemical parameters, in order to understand the variation of the biogeochemical properties during the open water and freezing periods.

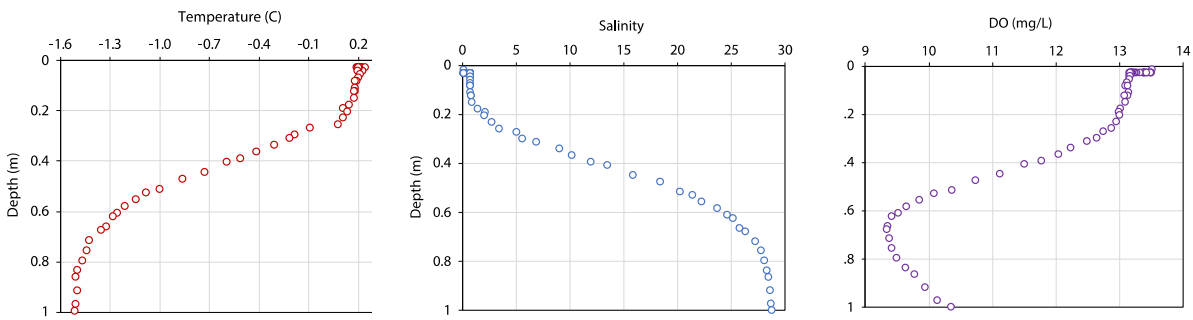


Figure 8.1.4. Vertical profiles of temperature (left), salinity (middle), and DO (right) in the melt pond (1st September 2020, MP 4a).

Ice coring in the melt pond (Team BGC)

Following sampling over several weeks, St. MP4 was sampled destructively on the 12th September, where samples were collected of surface ice and the water column, and the bottom of the melt pond was cored. The ice core collected at the bottom of the melt pond (MP 4b) was 72 cm in total length, and porous at the top 50 cm (Figure 8.1.5). Following melting in gas- tight bags, the ice melt water for this ice core, especially at the top section, contained significant amount of organic materials within the melt water. In the future, we will analyze the biogeochemical parameters within ice melt water in order to understand the effect of the sedimented organic material layer on the melt pond bottom (surface of the melt pond bottom ice) on the biogeochemical parameters within ice and interaction with the melt pond water. In addition, we also obtained the ice core to examine the ice physics (density, thick section, and micro-CT scan etc.) to compare with the biogeochemical parameters within ice.

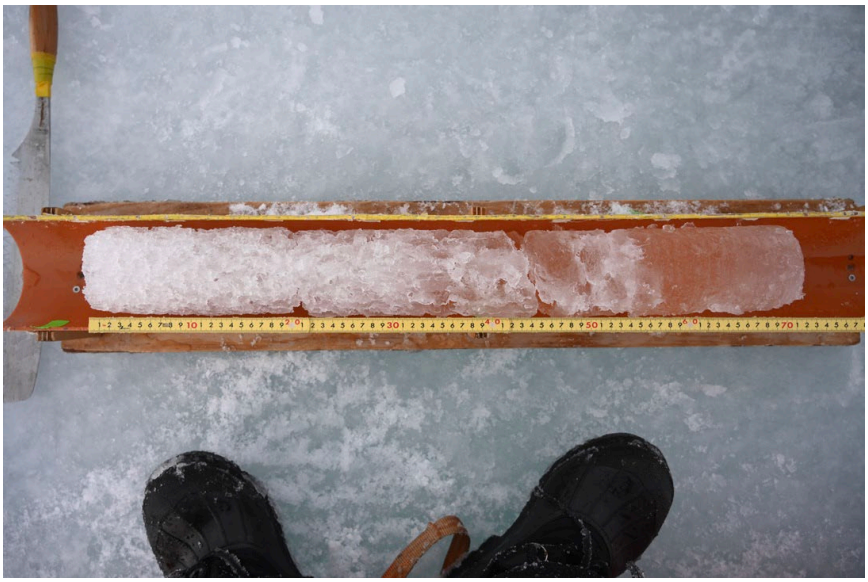


Figure 8.1.5. Pictures of the melt pond bottom ice core collected from the bottom of the melt pond (MP 4b) by using ice corer. Left side is the top of the ice core.

Gas flux chamber measurements and mixing experiment within the melt ponds (Team BGC & Team ATMOS)

Gas flux chambers from teams BGC and ATMO were installed both within the melt pond with floating chamber systems and over the melt pond ice surface (Figure 8.1.6; Table 8.1.4). CO_2 flux was measured within the melt pond with a floating chamber system (Figure 8.1.6). Because CO_2 concentration within the melt pond surface (top 10 cm) was low (approximately 321 ppm) as compared to the atmosphere (approximately 400 ppm), air–melt pond CO_2 flux was negative (melt pond was sink for atmospheric CO_2) by about –3.9 mmol m^{-2} day^{-1}. We also found that extremely low CO_2 concentrations (approximately 170 ppm) at the interface between freshwater and seawater (approximately 0.6 m depth), at the same depth as the DO minimum. Therefore, we expected that if melt pond water will be mixed vertically by the wind, cooling, crack formation, and ice movement, the melt pond atmospheric CO_2 absorbance will increase to compensate for the lower integrated CO_2 concentration. To study this process, the melt pond water of MP 4a was artificially-mechanically mixed on 2 September 2020, with water and gas flux samples collected before and after the mixing for comparison ("melt pond mixing experiment"). As a result of the mixing and the vertical convection, surface salinity and CO_2 concentration changed from 0.8 to 6.5 psu and 321 to 81 ppm, respectively. In addition, CO_2 flux changed from –3.9 to –21.0 mmol m^{-2} day^{-1}. As we expected, the environment of the surface of the pond changed following mixing, and the magnitude of the negative CO_2 flux increased dramatically. It is assumed that the freshwater and seawater mixing produce extremely low CO_2 concentration water (81 ppm) due to dilution effect rather than conservative mixing of water between 321 to 170 ppm of CO_2. Therefore, the mixing of the water within the melt pond provides the strong sink for atmospheric CO_2 and it is likely that the melt pond water has a potential to absorb significant amounts of CO_2 from the atmosphere. We have also examined this kind of mixing experiment for other parameters such as DMS, CH_4, N_2O, CO in the lead area (ROV Lead, 5 September 2020; see Chapter 8.2) and will compared for each parameter and area in the future. For details on the flux measurements by the ATMO Team, see Chapter 3.5.

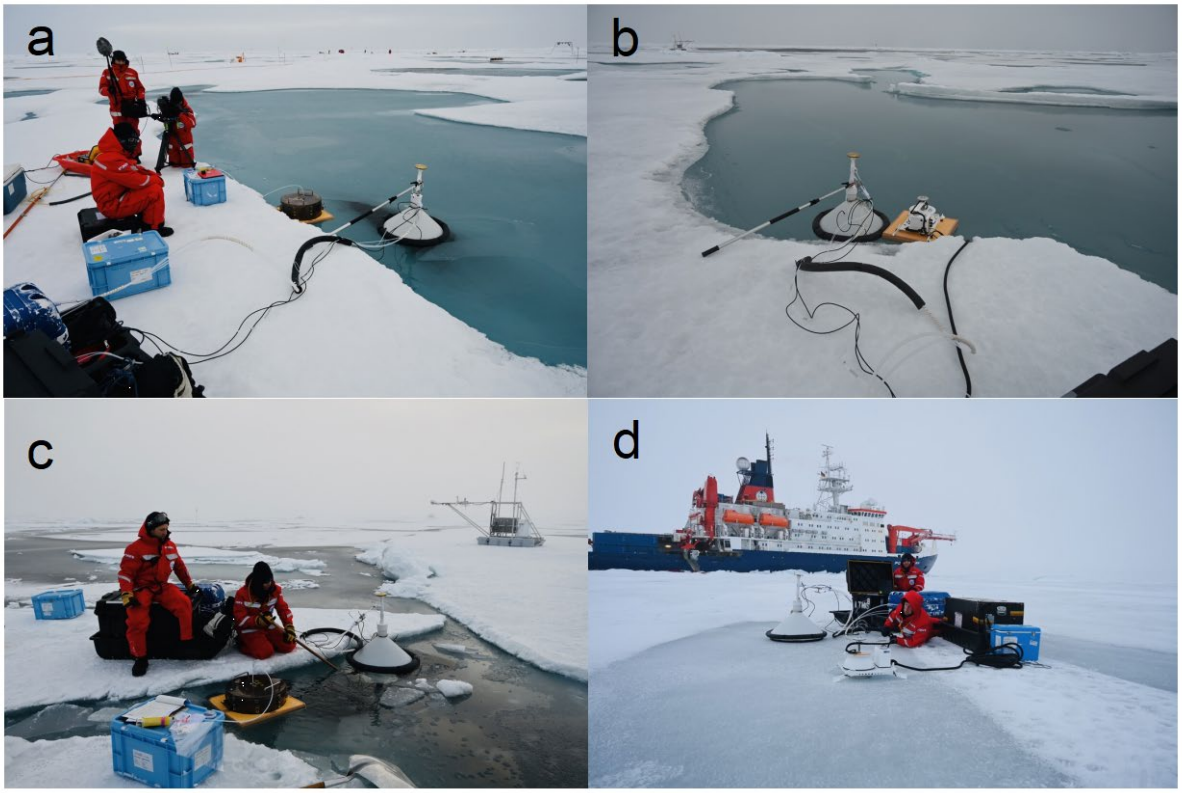


Figure 8.1.6. Flux chamber measurement in the melt pond with the floating chamber with team ATMO (a: MP 4a, 2 September 2020, b: coring site, 31 August 2020, c: ROV Lead, 5 September 2020, d: Ice station during transit: 24 September 2020).

Table 8.1.4. Chamber deployment and optical measurements in melt pond by Teams BGC and ATMO.

Date Collected	Location	Surface condition	Chamber/comment	Device operation ID related
22 Aug. 2020	Melt Pond by MetCity	Melt pond ice	ATMO gas chamber	PS122/5_59-364,59-365
25 Aug. 2020	Melt Pond by MetCity	Melt pond water (float)	ATMO gas chamber	PS122/5_59-450, 59-452
28 Aug. 2020	MP 4a	Melt pond water (float) and ice	ATMO gas chamber	PS122/5_59_469, 59_470, 59_471, 59_472
31 Aug. 2020	Ice coring site and near melt pond	Snow/melt pond water (float)	BGC gas chamber and ATMO gas chamber	PS122/5_60-17, 60-3, 60-181,60-182
1 Sep. 2020	MP 4a	Melt pond water (float)	ATMO gas chamber	PS122/5_60-185, 60-186
2 Sep. 2020	MP 4a	Melt pond water (float)	BGC gas chamber (metal) and ATMO gas chamber	PS122/5_60-61, 60-191, 60-192, 60-193, 60-194
2 Sep. 2020	MP 4 and MP 5	Melt pond water	Spectral albedo measurements with ASD	PS122/5-60-54

7 Sep. 2020	Ice coring site and near melt pond	Snow/freezing pond ice/pond water (float)	BGC gas chamber	PS122/5_61-6
24 Sep. 2020	Near PS	Snow/freezing melt pond ice	BGC gas chamber and ATMO gas chamber	PS122/5_63-324

Ice coring in the melt ponds (Team BGC & Team ATMO)

The melt ponds were sampled for surface and bottom ice at MP 4b on the 12th September 2020, MP4a on the 14th September, and MP1 on the 18th September 2020 (Table 8.1.3). Following melting in gas-tight bags, the ice melt water from these samples, especially in the pond bottom ice, contained significant amounts of organic material. Ice cores were taken through the ice underlying the melt pond, split into 10 cm sections in the field, and melted under gas tight conditions on return to the ship. Figure 8.1.7 shows the vertical profiles of the salinity of ice core collected at MP 4a and MP 1. For both sites, profiles of salinity were similar and decreased with depth, with the highest salinity at the top of the melt pond bottom ice due to the highly porous structure (Figures 8.1.8 and 8.1.9) and affected by the high salinity melt pond water. At the bottom of the pond bottom ice, ice was the standard multi-year ice structure seen in other ice cores around the floe, and salinity was low. We also obtained and sectioned ice cores to examine ice physics (density, thick section, and micro-CT scan etc.) to compare with the biogeochemical parameters within ice.

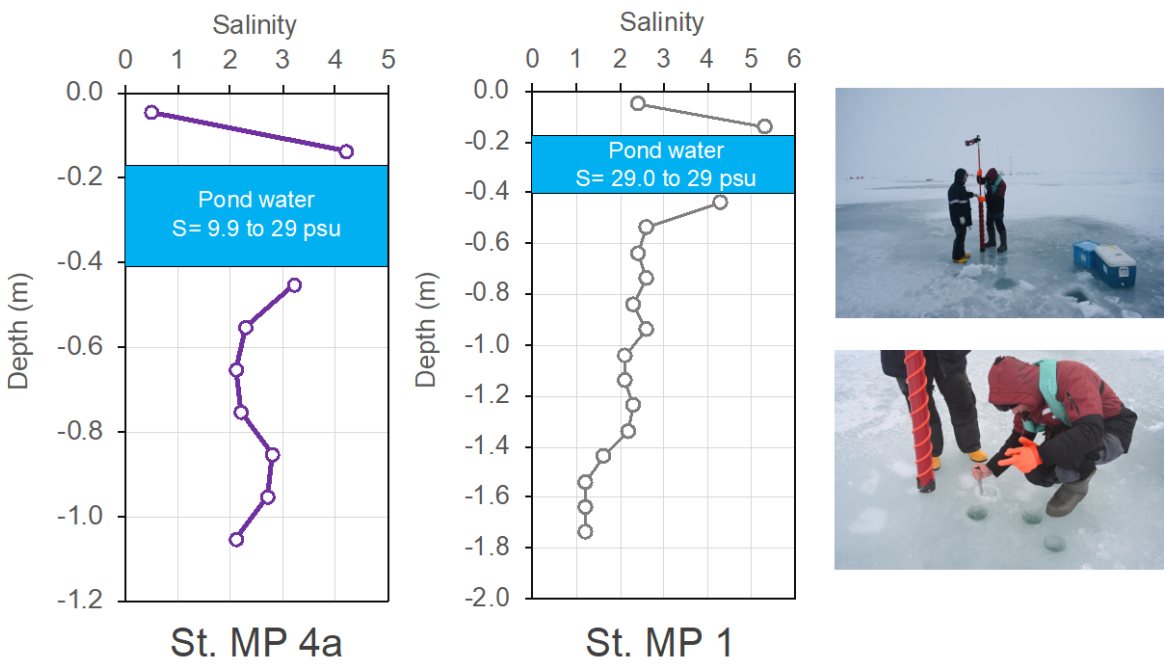


Figure 8.1.7. Vertical profiles of ice bulk salinity for the melt pond surface ice (between 0 and 0.2 m) and melt pond bottom ice (between 0.4 to 1.8 m) collected at MP 4a and MP 1. Pictures were from MP 4a.

Figure 8.1.8. Pictures of the horizontal section for the melt pond bottom ice (MP 1). Left side is top of ice core and right side is bottom of ice core.

Figure 8.1.9. Pictures of the vertical section for the melt pond bottom ice for top 0.3 m (MP 1). Left side was top of ice core.

Optical properties of melt ponds (Team ICE)

Optical properties MP 4 and MP 5 were investigated on 2 September 2020. The resulting spectral albedo from the ASD shows relatively lower values of spectral albedo in ponded areas that were completely melted through (Figure 8.1.10). For related physical and optical measurements of melt ponds, please see Chapter 4.9, and for ICE Optics Program, see Chapter 4.8.

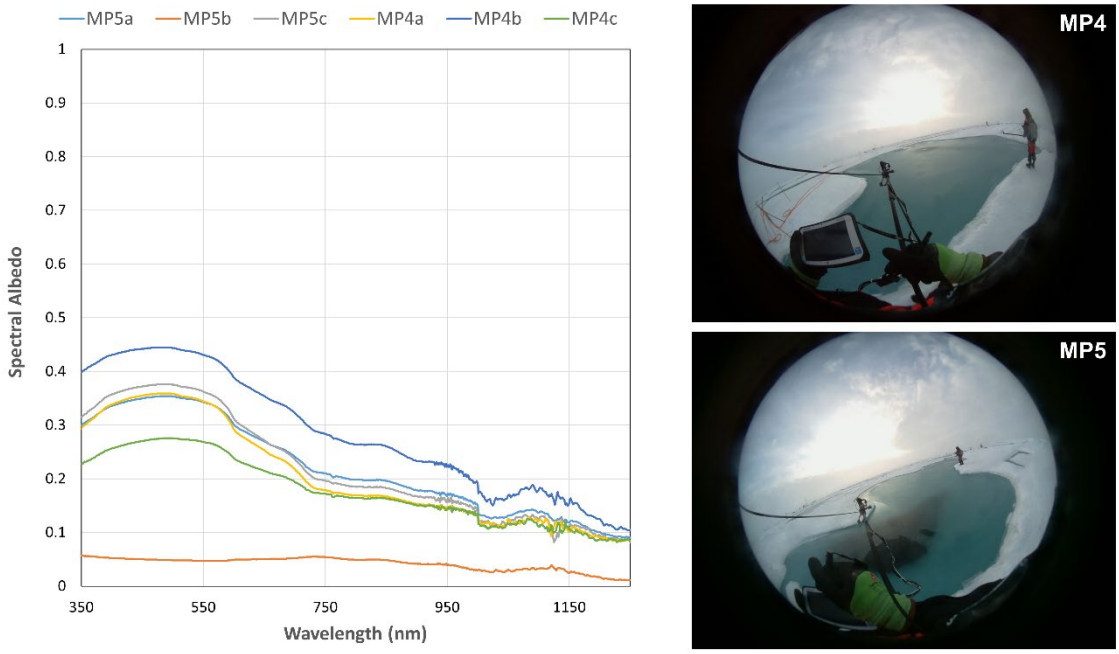


Figure 8.1.10. Spectral albedo values from melt pond stations 4 and 5 on 2 September 2020. The results shown were collected with an ASD, while the photographs were collected from the Stickle set-up. As seen in the photographs, the light conditions were variable.

Data Statement

In the case where analyses were done onboard, raw data files for further processing have been stored in the respective event folders within the MCS. For samples to be analysed at the respective home laboratories, they will be processed and stored in the MCS approximately after analysis. Processed data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science, www.pangaea.de) or other public data repositories that have an agreement with the MOSAiC Project leadership. In the latter case, DOIs will be communicated to PANGAEA for later access via the future MOSAiC Data Portal. All data are handled, documented, archived and published following the MOSAiC data policy.

8.4 LEADS (CROSS CUTTING)

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Maddie Smith[18], Morven Muilwijk[5], Sandra Tippenhauer[2], Deborah Bozzato[19], Oliver Mueller[5], Katy Shoemaker[20], Alessandra

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[10]UK.WARWICK
[11]UK.UNI-Plymouth

D'Angelo[20], Steve Archer[15], Aikaterini Tavri[21]
(not on board)

[12]EDU.UAF
[13]DE.CAU
[14]RU.AARI
[15]ORG.BIGELOW
[16]EDU.CU
[17]NO.UIT
[18]EDU.UW
[19]RUG
[20]EDU.URI
[21]Uni Victoria, CA

Objectives

Leads act as a dynamic intersection in the Arctic ice-ocean-atmospheric system and studying their properties and processes was a point of interest for almost all of the MOSAiC scientific teams. See section 8.4 of the PS122.4 cruise report for the motivating objectives and questions which initiated coordinated interdisciplinary lead sampling on MOSAiC Leg 4. This cross-cutting sampling effort continued on Leg 5, with additional questions surrounding an observed evolution and eventual destabilization of fresh meltwater lens layer, its implications for air-ocean exchange and biologic activity and impacts on new ice formation and other freeze processes.

Work at sea

Site descriptions

Five different lead sites were visited throughout the 4 science weeks of Leg 5 in an effort to capture lead evolution and freeze processes across both a spatial and temporal scale. Additionally, various leads were visited during the 2 ice transit stations during week 63.

- **Remote Sensing Lead (RS)**: Originally a crack in the floe, this lead opened up on approximately 24/08/20 resulting in a re-orientation of the ship. Just aft of the ship and next to the Remote Sensing site, this lead was visited frequently during the first half of Leg 5 by almost all teams. Often, at least two stations (numbered stations 3 and 8, originally part of the melt pond survey, see chapter X.X.X) were sampled to understand heterogeneity within the lead. By the end of Leg 5, RS Lead was completely frozen over and mostly closed.
- **ROV Lead (ROV)**: A partially frozen, partially open water lead adjacent to the ROV Oasis survey area was visited a few times in early September before eventually closing. Sampling region chosen near a MET ASF50 sled.
- **Sea Ice Formation Site or "Luna" Lead (Luna):** While most leads surrounding the MOSAiC Leg 5 floe were smaller in size and dominated by a fresh melt-water lens, this patch of semi-open water approx. 700m away from the ship (3:00 position) served as a representative "larger" lead and new sea ice formation site undisturbed by the ship. While it shrank in size over the course of Leg 5, unlike the other sites, the upper 1m of the water column was already well mixed in early September (>28 ppt salinity at surface) and many different ice types (nilas, grease, platelet, sheet, etc.) were observed developing over the second half of Leg 5.
- **Ocean City Lead (OC):** Located near the Ocean City sampling tent and Eco-Lodge sampling sites, this lead was first visited on 29/08/20. It then closed for most of the first half of Leg 5, forming a ridge near Met City. Opening again during a wind event in the early morning of one of the Intense Observation Periods (see description X.X.X), this

now non-stratified lead then quickly refroze and became a standard measurement site for the latter half of Leg 5.

- **Ship Lead (Ship):** A large open-water lead persisted adjacent to the ship in late September, providing an opportunity for open water sampling of turbulence and gas exchange. Sampling conducted from a Zodiac to avoid ship disturbance.
- **Ice Station 2:** Two leads (“Puffy” and “Ninja”) were visited for ice and water sampling during the 2nd marginal ice zone station along the exit transit south. Another lead was visited for gas fluxes and turbulence profiles.
- **Ice Station 3:** During the final marginal ice zone station during the exit transit, a final lead was visited for gas flux measurements.

Fig. 8.2.1. Photos of ROV Lead (top left - 02/09/20), Luna Lead (top right 04/09/20), Ocean City Lead (bottom left, 08/09/20), RS Lead (bottom right, 25/08/20). Photos: E. Chamberlain

Imagery

GoPro video profiles of the upper meter of lead observation sites were collected from many sampling events to observe new ice formation, and characterize visual density structure and turbidity within the water column. Sites were also characterized with photographs and written descriptions upon initial and subsequent visits.

Table 8.2.1 Device Operation IDs for Go-Pro imagery from leads during Leg 5, MOSAiC

Date	**Site**	Device
		UW_GoPro
25/08/20	RS	PS122/5_59-295
25/08/20	RS	PS122/5_59-296
29/08/20	RS	PS122/5_59-422
29/08/20	RS	PS122/5_59-421
02/09/20	ROV	PS122/5_60-65

04/09/20	ROV	PS122/5_60-229
04/09/20	Luna	PS122/5_60-230
06/09/20	Luna	PS122/5_60-204
07/09/20	OC	PS122/5_61-291
12/09/20	OC	PS122/5_61-293
13/09/20	Luna	PS122/5_61-300

Near surface density gradients/freeze up processes

Observations of various aspects of water column structure were made in the upper water column of leads surrounding the floe in an effort to capture stratification features. Most prominently, the persistence and destabilization of a freshwater layer found in the upper 1m of the water column. Temperature and salinity measurements were taken at high resolution using a YSI Professional temperature and conductivity probe in addition to deeper profiles including dissolved oxygen concentrations with an ASTD103, JFE Rinko profiler.

A VMP upriser was used to study the turbulence at the surface of the ocean and examine the evolution of this layer during the freeze-up process. More details about the VMP measurements can be found in Chapter 5.

Table 8.2.2: CTD, YSI, and VMP Upriser Deployments in leads, Device Operation IDs, Leg 5, MOSAiC

Date	**Site**	Device		
		RINKO-pro_592	**Dart_YSI**	**VMP Upriser**
23/08/20	RS	PS122-5_59-223	ND	PS122-5_59-275
23/08/20	RS	PS122-5_59-230	ND	ND
24/08/20	RS	PS122-5_59-258	ND	ND
24/08/20	RS	PS122-5_59-260	ND	ND
25/08/20	RS	PS122-5_59-297, 298	PS122/5_59-293	ND
25/08/20	RS	PS122-5_59-417	PS122/5_59-294	ND
27/08/20	RS	ND	ND	PS122-5_59-325
28/08/20	RS	ND	ND	PS122-5_59-380
29/08/20	OC	PS122-5_59-418	PS122/5_59-414	ND

29/08/20	RS	PS122-5_59-419, 420	PS122/5_59-415, 416	PS122-5_59-381
30/08/20	RS	ND	ND	PS122-5_59-382
31/08/20	RS	ND	ND	PS122-5_60-36
02/09/20	RS	ND	ND	PS122-5_60-37
02/09/20	ROV	ND	PS122/5_60-63	ND
04/09/20	Luna	ND	PS122/5_60-228	ND
04/09/20	ROV	PS122-5_60-147	PS122/5_60-227	PS122-5_60-85
05/09/20	ROV	PS122-5_61-148	ND	PS122-5_60-218
06/09/20	ROV	ND	ND	PS122-5_60-219
06/09/20	Luna	ND	PS122/5_60-203	ND
07/09/20	OC	ND	PS122/5_61-66	PS122-5_60-220
08/09/20	OC	PS122-5_61-272	ND	PS122-5_61-24
09/09/20	OC	ND	ND	PS122-5_60-179
11/09/20	OC	ND	ND	PS122-5_60-180
12/09/20	OC	ND	PS122/5_61-294	PS122-5_60-181,245
13/09/20	OC	ND	ND	PS122-5_60-246
13/09/20	Luna	ND	PS122/5_61-301	ND
14/09/20	OC	ND	PS122/5_62-196	ND
14/09/20	Ship	ND	ND	ND
15/09/20	RS	PS122-5_62-41	ND	ND
15/09/20	Ship	ND	ND	PS122-5_60-110
16/09/20	Ship	ND	ND	PS122-5_60-112
17/09/20	Ship	ND	ND	PS122-5_60-113
18/09/20	OC	ND	PS122/5_62-223	ND

*ND stands for “Not Deployed”.

Water Sampling

On Leg 5, teams ECO & BGC collected water samples to investigate the biogeochemical cycling of carbon and other climate relevant trace gasses as well as the ecological properties which influence the production, sequestration, and fluxes of these gasses in leads and across the ice, ocean, atmosphere interphases. Ecological observations aimed to measure standing stocks of organisms and organic matter (chl a, POC/PON), microbial/protistan diversity and abundance (light microscopy, FCM, DNA), and production rates in relation to nutrient availability (NCP, PP, BP, nuts). In parallel, the concentrations and isotopic ratios of key gasses were measured. The following common parameters were collected from 1-4 shallow horizons depending on observed water characteristics at the time of collection. (i.e. visible biomass and/or stratification within temperature and salinity profiles).

- 14C-NPP and 3H-BP rates – primary productivity and bacterial production (if possible)
- NCP - Net Community Production estimated by biological oxygen saturation (O2/Ar)
- Total DNA – microbial diversity
- Light Microscopy – plankton taxonomy
- Flow Cytometry (FCM) – single cell organism enumeration
- Chlorophyll a – photosynthetic biomass
- DOC/cDOM - dissolved organic carbon/colored or chromophoric dissolved organic matter
- Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA)
- Pigment biomarkers/HPLC
- Inorganic Nutrient, and TDN, TDP concentrations – nutrient inventories, availability, and recycling processes
- N_20 concentrations
- DMS/DMSO/$DMSP_t$ - concentrations and production experiments
- CH_4/CO_2 - concentrations and isotopic signatures (less frequent)
- ^{18}O and Deuterium isotopic signatures
- Aerosol production experiments

Table 8.2.3.: Water sampling from leads - Device operation ID, MOSAiC Leg 5

Deployment Date	Site	Device		
DD/MM/YY		Peristaltic_Pump	Hand_Pump	Water_Sampler
22/08/20	RS	PS122-5_59-203	ND	ND
22/08/20	RS	PS122-5_59-211	ND	ND
25/08/20	RS	PS122-5_59-290	PS122/5_59-291	ND
29/08/20	OC	PS122-5_59-389	PS122/5_59-391	ND
29/08/20	RS	PS122-5_59-392	PS122/5_59-393	ND
01/09/20	RS	PS122-5_60-22	PS122/5_60-22	ND
02/09/20	ROV	PS122-5_60-133	PS122/5_60-64	ND
04/09/20	ROV	PS122-5_60-130	PS122/5_60-131	ND
04/09/20	Luna	ND	PS122/5_60-223	ND

05/09/20	ROV	PS122-5_60-146	ND	ND
06/09/20	Luna	PS122-5_60-202	PS122/5_60-201	ND
07/09/20	OC	PS122-5_61-273	PS1122/5_61-64	ND
08/09/20	OC	PS122-5_61-272	ND	PS122/5_61-272
12/09/20	OC	PS122-5_61-126	PS122/5_61-295	PS122/5_61-278
13/09/20	Luna	ND	PS122/5_61-302	PS122/5_61-303
14/09/20	OC	ND	PS122/5_62-197	ND
15/09/20	RS	PS122-5_62-92	ND	ND
18/09/20	OC	ND	PS122/5_62-218	PS122/5_62-137
26/09/20	Ice Station 2	ND	ND	PS122/5_63-84

*ND stands for “Not Deployed”.

Atmospheric Measurements

In an effort to link the chemical, physical, and biological properties of the lead to trace gas fluxes (CO2, CH4, DMS), gas fluxes were measured to identify sources and sinks of these gases and the processes that govern their formation and fate. More information can be found in section 3.6 of the cruise report.

Table 8.2.4.: Flux Chamber (ID) Deployments on leads - Device operation ID, MOSAiC Leg 5

Deployment Date	**Site**	**Gas Species**	
DD/MM/YY		**CO2 and CH4**	**DMS**
25/08/20	RS	PS122/5_59-448	PS122/5_59-451
26/08/20	Met City	PS122/5_59-455	PS122/5_59-456
	Met City	PS122/5_59-459	PS122/5_59-460
27/08/20	Met City	PS122/5_59_463	PS122/5_59_464
	Met City	PS122/5_59_465	PS122/5_59_466
29/08/20	OC	PS122/5_59_473	PS122/5_59_474
	RS	PS122/5_59_475	PS122/5_59_476
01/09/20	RS	PS122/5_60-187	PS122/5_60-188
04/09/20	ROV	PS122/5_60-195	PS122/5_60-196

05/09/20	ROV	PS122/5_60-197, 146	PS122/5_60-198
	ROV	PS122/5_60-199	PS122/5_60-200
07/09/20	OC	PS122/5_61-16	PS122/5_61-17
	OC	PS122/5_61-18	PS122/5_61-19
	OC	PS122/5_61-20	PS122/5_61-21
08/09/20	OC	PS122/5_61-39	PS122/5_61-40
09/09/20	OC	PS122/5_61-118	PS122/5_61-119
14/09/20	Ship	PS122/5_62-76	PS122/5_62-77
15/09/20	Ship	PS122/5_62-78	PS122/5_62-79
	Ship	PS122/5_62-80	PS122/5_62-81
17/09/20	Ship	PS122/5_62-272	PS122/5_62-273
	Ship	PS122/5_62-274	PS122/5_62-275
26/09/20	Ice Station 2	PS122/5_63-271	PS122/5_63-272
30/09/20	Ice Station 3	PS122/5_63-275	PS122/5_63-276

*ND stands for “Not Deployed”.

Ice Formation

On Leg 5, emphasis in lead studies was placed on the freeze-up processes governing new ice formation across these open water surfaces and the impact of ice growth on processes such as heat partitioning, ecological turnover, and biogeochemical exchanges across the ocean, ice, atmosphere interface. To support this study, various ice types across all stages of growth were collected from each lead and processed for physical, biological, and chemical parameters. Ecological and biogeochemical measurements reflect those taken in the underlying water column (NPP, BP, DNA, Light Micro, FCM, Chl a, DOC/cDOM, Nutrients, DMS/DMSO/DMSPt, ^{18}O). Physical parameters include salinity, texture, micro CT, etc.

Remote sensing instruments were also used to measure on the floe at the lead near the remote sensing site (RS Lead) with the Balamis Microwave Radiometer Ariel to measure the thin ice conditions and ice growth in the early stage. In the beginning, we also set up the IR-Camera at the lead, but then moved it to another site. Thin ice observation at leads with these two instruments were part of the transects during the ice stations. Additionally, ice and snow/slush thickness measurements were taken as well as values for water salinity and

temperature. During the ice station also slush samples were analyzed for its salinity. For more information see the remote sensing Team ICE Chapter 4.12.

Table 8.2.5. Ice collection from leads, Device Operation IDs, MOSAiC Leg 5.

Deploy-ment Date	**Site**	**Device**		
DD/MM/YY		**SI_Ice_Sampler**	**SI_corer_14cm/9cm**	**Falcon_Tube**
29/08/20	OC	PS122_5 59-447	ND	ND
29/08/20	RS	PS122_5 59-446	ND	ND
01/09/20	RS	ND	ND	ND
02/09/20	ROV	ND	ND	ND
04/09/20	ROV	PS122/5_60-272	ND	ND
04/09/20	Luna	PS122/5_60-224	ND	ND
05/09/20	ROV	PS122_5 60-150	ND	ND
06/09/20	Luna	PS122/5_60-205	ND	ND
07/09/20	OC	PS122/5_61-65	ND	ND
08/09/20	OC	ND	ND	ND
12/09/20	OC	ND	PS122/5_61-262	PS122/5_61-296
13/09/20	Luna	ND	PS122/5_61-304	PS122/5_61-305
14/09/20	OC	PS122/5_62-42	ND	ND
15/09/20	RS	ND	PS122/5_62-138	ND
18/09/20	OC	PS122/5_63-83	ND	ND
26/09/20	Ice Station 2	PS122/5_63-85	ND	ND

Preliminary Results

Destabilization of the near-surface freshwater layer

13 detailed YSI temperature and salinity profiles of the upper water column were collected from leads over the course of Leg 5. Temperature stratification disappears from all sites after 09/07/20, with salinity stratification following soon after (Fig X.X.X) - indicating that around this time (coincident with a notable shift from melt to freeze processes as well as several wind events), the persistent freshwater lens that was documented both in Leg 4 at the MOSAiC Floe and in the beginning of Leg 5 at the new Floe destabilized and leads became well mixed. This noticeable shift was evident in the visual surveys as well as ice formation processes with a marked reduction in the presence of freshwater platelet ice under the surface freeze (Fig X.X.X).

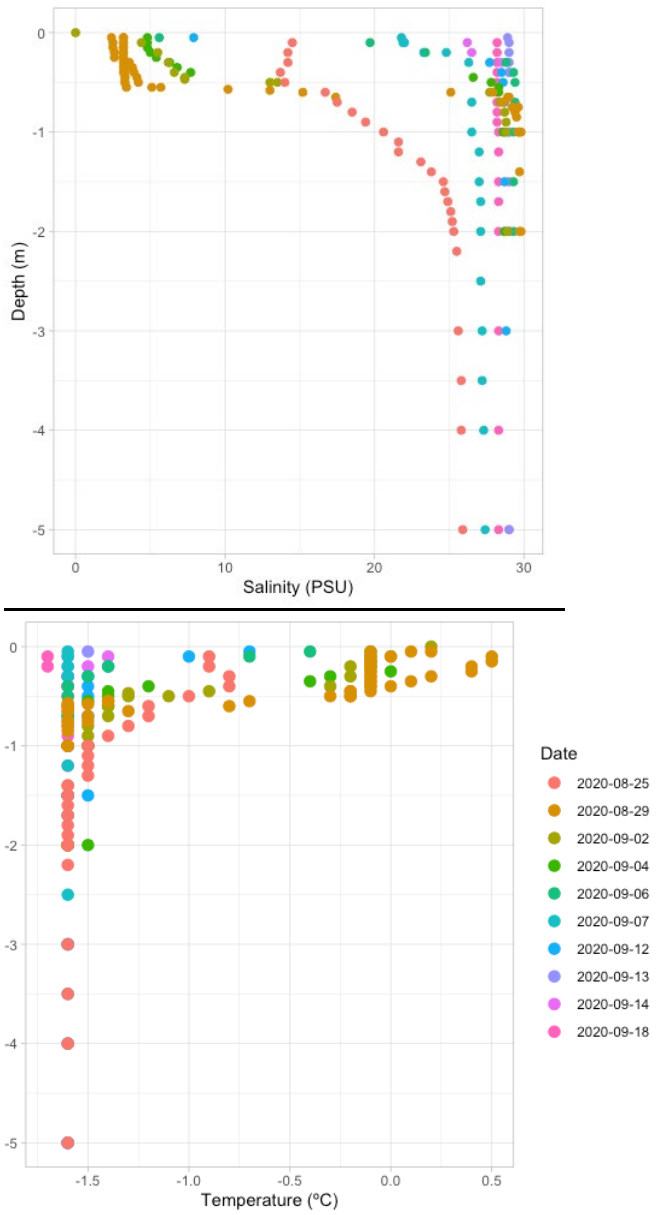

Fig 8.2.2 YSI probe temperature and salinity measurements from all leads in the upper 5 m of the water column from Aug 25th - September 18th. Figure: E. Chamberlain

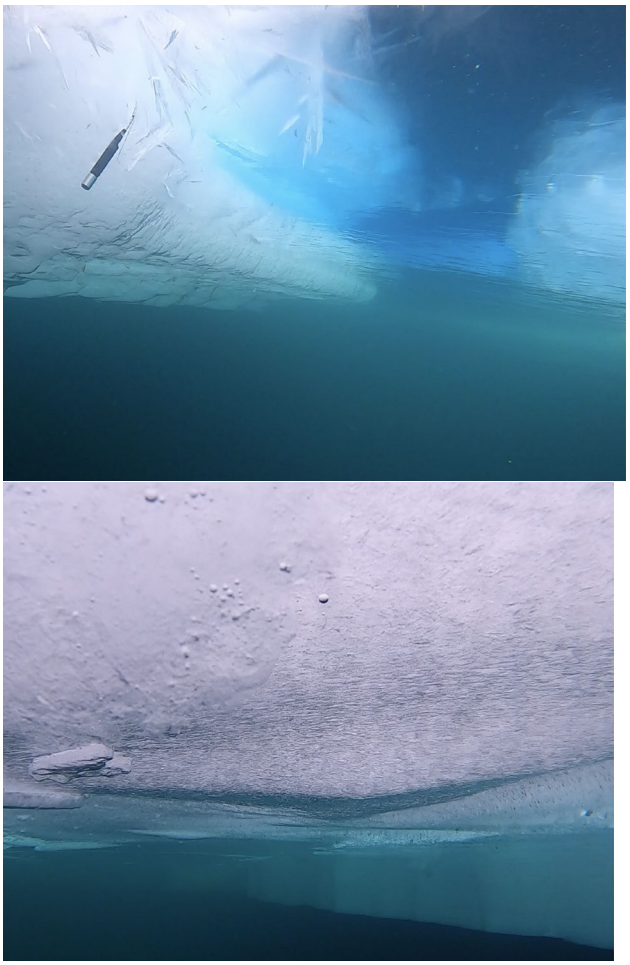

Fig 8.2.3 Visual confirmation of the destabilization of the stratified freshwater layer as seen in go-pro surveys from Ocean City on Aug 25th (left) and September 12th (right). Photos by E. Chamberlain

New ice texture between two leads

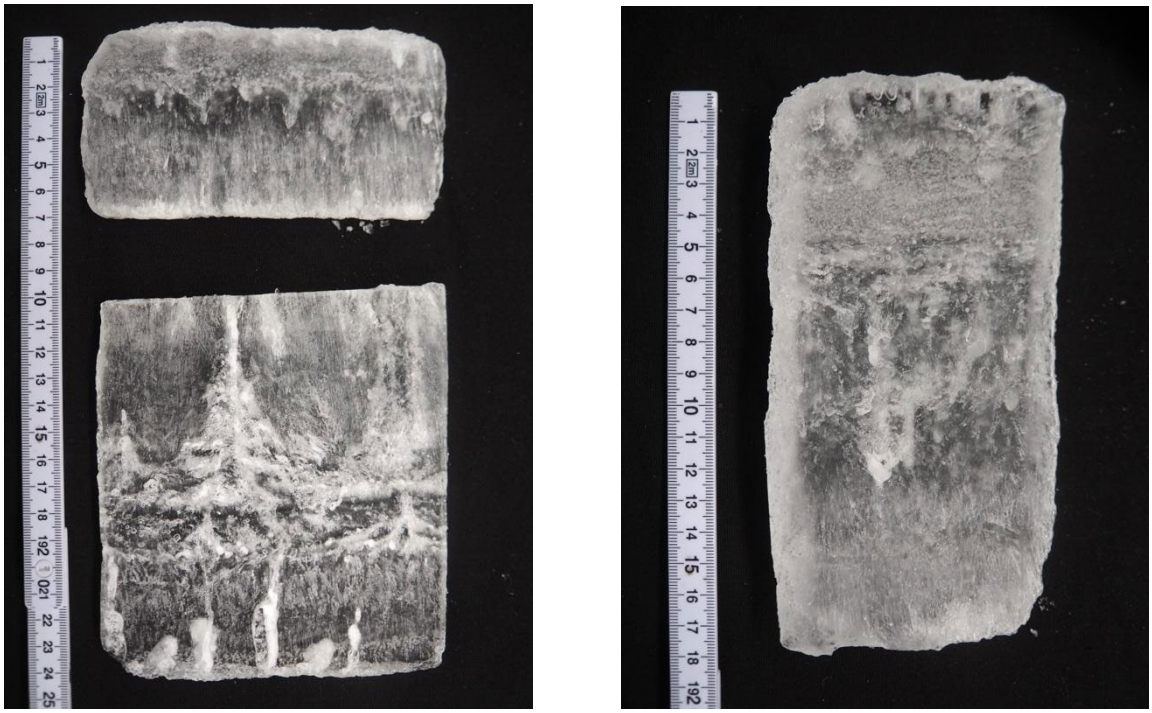

Figure 8.2.4 Texture cores collected from *(left)* RS lead and *(right)* OC lead on 2020-09-18

(Nikolai Kolabutin)

Data statement:

In the case where analyses were done onboard, raw data files for further processing have been stored in the respective event folders within the MCS. For samples to be analysed at the respective home laboratories, they will be processed and stored in the MCS approximately after analysis. Processed data will be stored at the PANGAEA data repository (World Data Center PANGAEA Data Publisher for Earth & Environmental Science, www.pangaea.de) or other public data repositories that have an agreement with the MOSAiC Project leadership. In the latter case, DOIs will be communicated to PANGAEA for later access via the future MOSAiC Data Portal. All data are handled, documented, archived and published following the MOSAiC data policy.