CRUISE REPORT

ARCTIC AND ANTARCTIC SEA ICE - THICKNESS VARIABILITY AND CHANGE, ICE LOADS, AND NAVIGABILITY

Le Commandant Charcot, Cruise No. CC110823, 2023-08-11 - 2023-08-26,
Longyearbyen (Svalbard) – Longyearbyen (Svalbard)

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Contents

1 Summary

We participated with our project “ARCTIC AND ANTARCTIC SEA ICE - THICKNESS VARIABILITY AND CHANGE, ICE LOADS, AND NAVIGABILITY” (PI: Christian Haas, Franz von Bock und Polach) in the Cruise NO CC110823 (2023-08-11/Longyearbyen to 2023-08-26/Longyearbyen). The project’s main goal is to study sea ice thickness, an important climate indicator and a crucial property affecting the energy and freshwater balance, ecosystem functions, and navigability of ice-covered waters. We conducted ship-based and on-ice measurements, surveying sea ice thickness and properties, surface roughness, leads, ridges, and melt pond coverage. We investigated the dynamic and thermodynamic processes affecting the sea ice thickness and the impact of sea ice thickness on the navigability in polar waters and ice loads. These measurements complement our long-term observations, expand the international buoy network, validate satellite data and models, and investigate ship-ice interactions and performance. Our main focus was on continuous underway measurements of ice and ship properties which were complemented with 4 ice stations for reference measurements and the deployment of autonomous measurement platforms on the ice. Further, we investigated the effect of temperature changes in polar waters on the ship’s structure. In addition to the direct load on the ship’s structure caused by the ice, the prevailing temperatures pose a particular challenge for the construction of ice-going ships.

2 Research Programme/Objectives

The project’s main goal is to study sea ice thickness, an important climate indicator and a crucial property affecting the energy and freshwater balance, ecosystem functions, and navigability of ice-covered waters. Our main focus was on sea ice thickness and surface topography measurements. Our primary objectives were to investigate the small-scale variability of sea ice thickness and to evaluate and contextualize the measurements obtained from the underway sea ice thickness measurements with the ultimate aim of upscaling them to compare them with satellite retrieval. The underway ice thickness measurements were complemented by recording visual images with two different cameras and surface roughness with a scanning laser. We aim to use the visual images to 1) quality-control the SIMS measurements, 2) interpret the SIMS data in a larger scale context, and 3) monitor the ice-ship interactions. The data from the scanning laser are used to derive surface roughness at a high spatial resolution. To extend our measurements beyond the expedition time, we deployed autonomous measurement platforms on the sea ice collecting continuous measurements of the sea ice and snow mass balance in our absence.

In addition to the sea ice thickness, properties, and surface topography measurements, we aimed to characterize the sea ice surface properties, including leads, ridges, floe sizes, and melt ponds. We collected aerial images with a drone, which can be classified to calculate the aerial fractions of the above-mentioned properties. When combined into orthomosaics and digital elevation models, the aerial images can also be used to characterize surface topography and melt pond depth. This way, we can comprehensively characterize the changes in the sea ice surface along a continuous transect from the ice edge to the central ice pack.

Furthermore, a long-term temperature measurement system already installed in 2022 was extended to investigate the effects of the Arctic climate on the ship’s structure. With this system, the temperature of the ship’s structure in the waterline area is recorded at selected positions on starboard and portside of the Le Commandant Charcot (LCC). This configuration makes it possible to measure the influence of solar radiation in addition to the global influence of the prevailing temperatures.

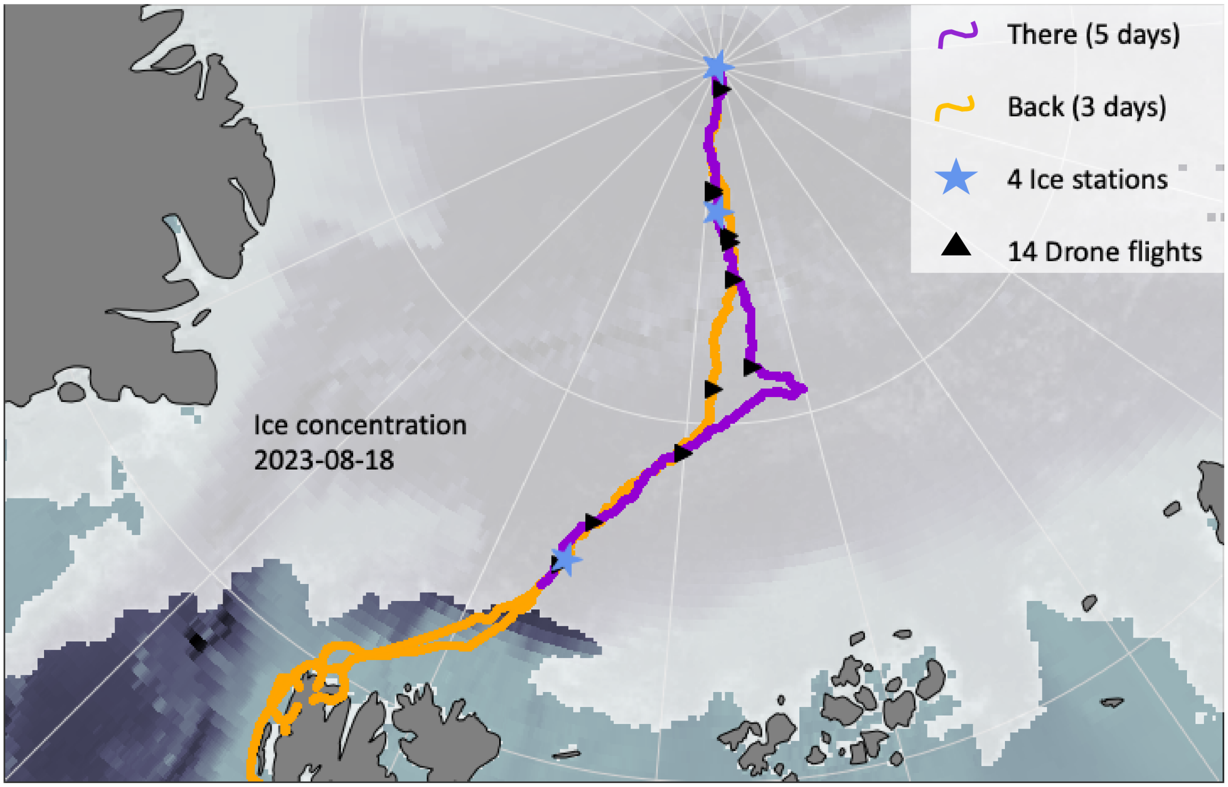

Figure 1. Cruise track of CC110823 overlaid on a map of the Arctic. The location of the ice station and drone flights are marked. Arctic bathymetry from RTopo (Schaffer and Timmermann, 2016). Sea ice concentration from 2023-08-18 was downloaded from seaiceportal.de (Grosfeld et al., 2016)

3 Narrative of the Cruise

The work at sea of this project consisted of three components of field observation: (1) continuous measurements on and from the vessel (2) station work on sea ice and from the vessel, and (3) deployments of autonomous devices on sea ice for continuous measurements beyond the expedition time. In addition, instrument preparation, data monitoring, and data processing were conducted while being on board LCC. The major part of this project was conducted during cruise No CC110823 while two project members were on board. We collected underway measurements while sailing in the ice pack between 2023-08-12, 20:55, and 2023-08-20, 20:10 (Figure 1). In addition to several stops to perform drone flights and thermal infrared scans of the ship (see Table 2), we worked on the ice during four ice stations on 2023-08-15 (Station 1, 87.56/49.22), 2023-08-16 (Station 2, 89.98/117.23), 2023-08-17 (Station 3, 89.99/34.75), and 2023-08-20 (Station 4, 82.80/27.90). During cruise No CC260823 (2023-08-26 – 2023-09-10) the science officer deployed additional autonomous platforms for this project at the North Pole.

3.1 Continuous measurements on and from the vessel

While sailing in ice, we autonomously collected properties of the surrounding ice (thickness, surface type, and roughness), the motion of the ship, and the temperature of the outer shell of the ship's structure at selected positions.

3.1.1 Sea ice thickness measured by the SIMS

We carried out ship-based ice thickness observations using the onboard Sea Ice Monitoring System (SIMS) and evaluated and calibrated the instrument with additional measurements (in-situ ice thickness measurements, CTD cast). This way we quality-control the data collection with the SIMS during all upcoming North Pole voyages of LCC. The SIMS consists of two major instruments: a sonar recording the distance to the air/snow interface and an EM31 recording the distance to the ice/ocean interface. The SIMS is located in front of the ship's bow (see Figure 2). Upon arrival on the ship, we reinstalled the original LCC EM31 within the SIMS which had returned from the manufacturer. However, since the LCC EM31 failed to power up, we were forced to reinstall the AWI EM31. The SIMS (with the AWI EM31) was deployed before reaching the ice edge and removed after leaving the ice. It collected data from 2023-08-12 16:50 to 2023-08-21 14:17. A data gap may exist between 2023-08-13 20:11:37 and 2023-08-14 08:11 (to be confirmed). We performed four calibrations:

- 2023-08-12: Calibration over open water after initial deployment, utilizing new coefficients afterward.
- 2023-08-13: Calibration over open water following an anomaly in ice thickness data, utilizing new coefficients afterward.
- 2023-08-17: Calibration over sea ice for comparison with in-situ ice thickness estimates.
- 2023-08-21: Calibration over open water before instrument retrieval.

We collected additional datasets to quality-control the SIMS measurements:

- 2023-08-15 10:28: GEM measurements beneath the SIMS.
- 2023-08-16 16:00: Manual ice thickness drilling below the SIMS.
- 2023-08-17 10:00: Manual ice thickness drilling below the SIMS.
- 2023-08-21 11:47: CTD cast of the upper 10 m of the ocean for water conductivity

The SIMS ice thickness data were complemented by visual images and laser scans of the surveyed ice (see Sections 3.1.3-3.1.4). Snow thickness estimates are available from the four ice stations.

3.1.2 Ship motions measured by the DMU

The Dynamic Motion Unit (DMU) is used to record the accelerations in all three dimensions (x, y, and z) as well as the ship's motions roll, pitch, and yaw rate. In combination with the SIMS (see Sections 3.1.1) and the cameras (see Sections 3.1.3), this measurement setup will be used to investigate a correlation between the ice breaking and the resulting ship motions.

The DMU was installed at the bow of the ship on deck 4 at frame 180 close to the SIMS before reaching the ice edge and removed after leaving the ice. It collected data from 2023-08-12 17:27 UTC to 2023-08-21 07:00 UTC. The recording of the measurement data was carried out with a Peekel Autosoft 3000 measurement data acquisition system with a frequency of 10Hz.

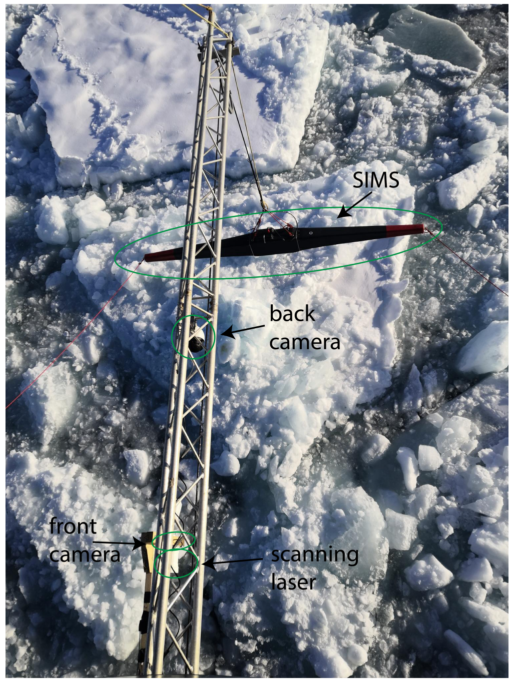

Figure 2. Instruments measuring at the ship's bow. The SIMS is mounted on a metal boom. The back camera is fixed to the metal construction. A wooden stick attached to the metal construction supports the front camera and the scanning laser.

3.1.3 Sea ice surface type - Visual images from time laps Cameras

The underway ice thickness measurements from the SIMS and the ship motions measurement from the DMU were complemented by visual images from two time laps (manufacturer: Reolink) cameras. The front camera was installed on a wooden stick attached to the SIMS mental structure. The back camera was installed directly on the metal structure of the SIMS. Figure 2 shows all instruments at the bow. The front camera monitored the ice below the SIMS and in the surroundings and the back camera viewed the ship's bow. We aimed to use the visual images to (1) quality-control the SIMS measurements, (2) interpret the SIMS data in a large-scale context, and (3) monitor the ice and its shape that hits the ship's bow. The front camera recorded images with a frequency of 10Hz from 23-08-13 16:47 – 2023-08-21 6:24 UTC. The back camera recorded images with a frequency of 4Hz from 2023-08-12 16:41 UTC to 2023-08-21 21:47 UTC. In addition to installation and de-installation, we performed daily routine checks and downloaded the data.

3.1.4 Sea ice surface roughness – Velodyne scanning laser

The data from the scanning laser (Velodyne) are used to derive surface roughness at a high spatial resolution. The scanning laser was installed together with the front camera on the wooden stick connected to the metal structure of the SIMS (Figure 2). We collected scanning laser profiles from 2023-08-13 16:50 – 2023-08-21 06:24 UTC with a gap on 2023-08-15 18:00-20:17 UTC and 2023-08-17 07:04-18:02 during Station 3.

3.1.5 Temperature loggers of ship's hull

The outer hull of the LCC is instrumented with temperature sensors at selected positions. On the starboard side in the wet lab at frame 81, as well as in the void spaces below were the sensors already installed during a cruise to the North Pole last year (see Figure 3). Necessary maintenance work was carried out on these sensors on 2023-08-11 and the data collected in the meantime was downloaded. On the port side in the garbage treatment room at frame 81, as well as in the void spaces below new sensors were installed on 2023-08-11 (see Figure 4).

These measurements aim to determine the temperature distribution in the ship's side structure in the area of the waterline as a function of the outside air, ice, and water temperatures as well as the interior temperature. Specially developed PT-1000 elements from Driesen+Kern GmbH are used as temperature sensors for measuring the ship's structure temperature. The temperature sensors are measured with DK311 (single-channel) and DK312 (dual-channel) as well as DCXP8R (8-channel) and DCXP16R (16-channel) data loggers from Driesen+Kern GmbH. The acquisition and recording of the measurement data takes place once every five minutes and is designed as a long-term measurement that remains on board and continues to record measurement data even after this cruise.

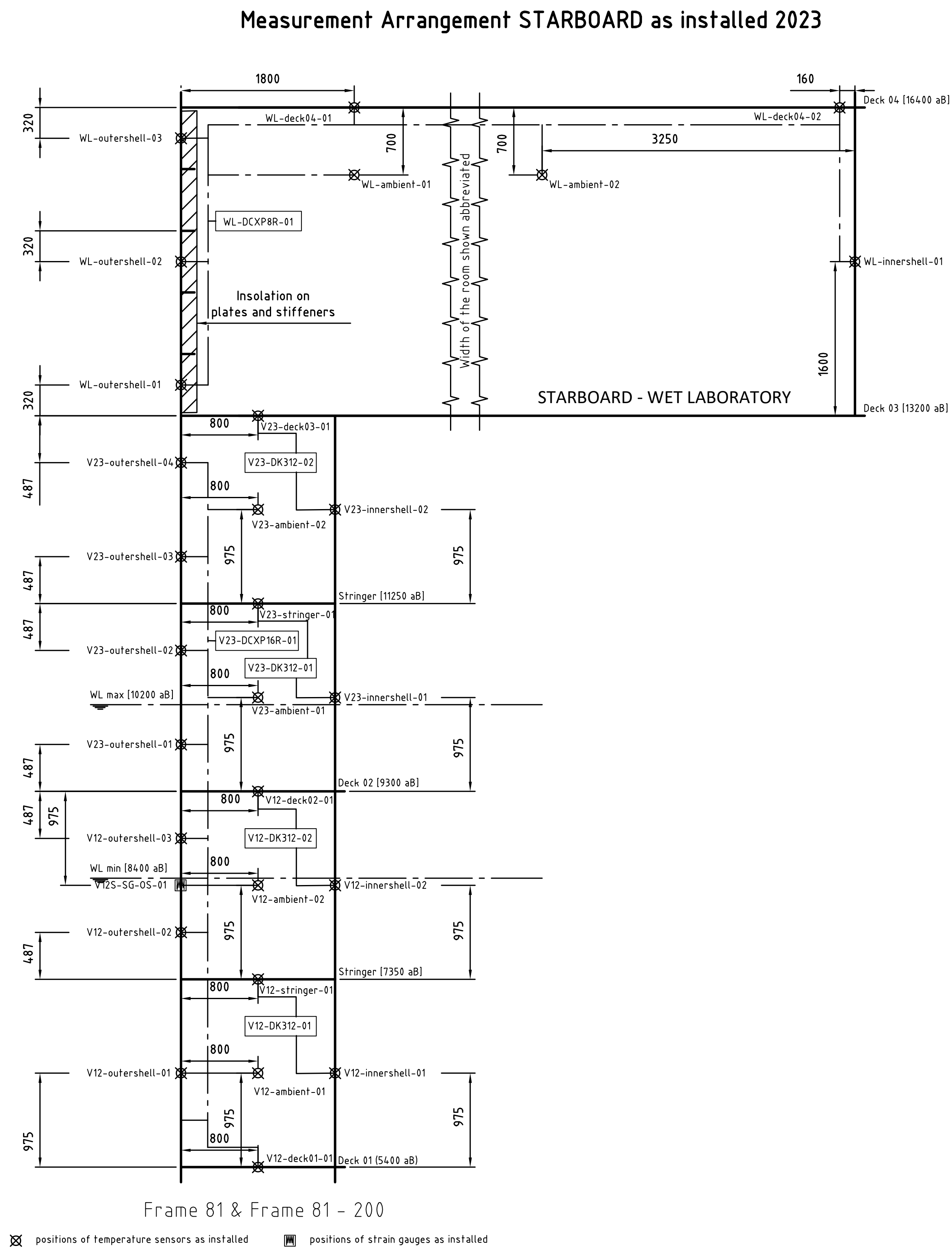

Figure 3. Positioning and naming of the temperature measuring points on the starboard side.

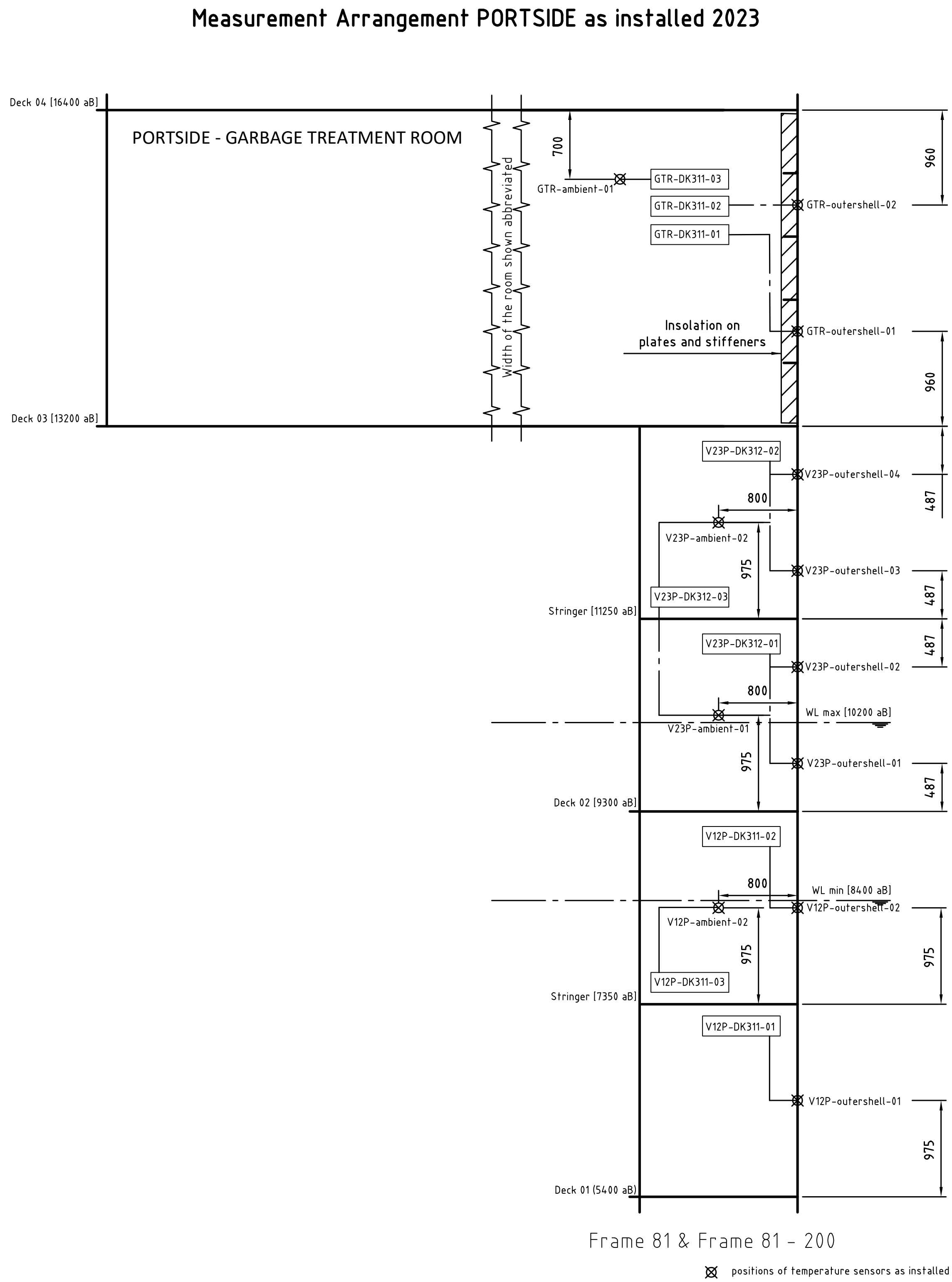

Figure 4. Positioning and naming of the temperature measuring points on the port side.

3.2 Station work on sea ice and from the vessel

When the ship was stationary, we worked from the vessel (drone flights), from zodiacs in open water (thermal infrared scans), and on the ice (ice stations).

3.2.1 Sea ice surface properties and roughness based on aerial photographs: drone flights

We flew a drone (type: Mavic3 from DJI) equipped with a visual camera from the vessel and the ice. The drone images allow us to capture ice features such as ridged ice, melt ponds, open-water areas, floe sizes and shapes, and surface roughness at a spatial resolution in the centimeter range. The images with an overlap of > 80% are used to generate high-resolution Digital Elevation Models (DEMs) and orthomosaics. When time allowed, we additionally conducted flights to estimate the short-term variability in sea ice drift, achieved by capturing images while the drone was stationary amidst drifting ice. Last, we investigated the scaling behavior in critical properties like albedo, melt pond coverage, and surface roughness, by capturing images during a continuous ascent.
We conducted 14 drone flights, adopting three distinct flight patterns tailored to different scientific goals:

- grid patterns with >80% overlap to facilitate the creation of precise DEMs and orthomosaics (10 flights).
- Stationary flights, capturing imagery of drifting ice to assess short-term drift variability (2 flights).
- Imagery acquisition at varying scales (1 flight).
- Single shots of ice characterizing the coring site at ice station 4 (1 flight).

Drone operations on board consisted of the following steps:

- Pre-flight preparations (coordination with the ship, charging batteries, weather condition check).
- 1-2 drone flights of max. 15 minutes with different patterns when the ship was stationary
- Post-flight documentation of flight conditions and downloading data.
- Processing of single photographs into orthomosaics and digital elevation models using commercial software (Metashape).

3.2.2 Sea ice thickness: GEM

During the on-ice stations, we surveyed the ice thickness with a sledge-mounted EM system towed on the ice, referred to as GEM. We aimed at two types of GEM surveys: (1) Grid patterns to characterize the surrounding ice and (2) Point measurements below the SIMS.
We conducted GEM surveys on:

- 2023-08-15 / Station 1: Grid survey of the floe and point measurement below SIMS
- 2023-08-17 / Station 3: Grid survey of the floe and point measurement below SIMS
- 2023-08-18 / Station 4: Grid survey

3.2.3 Manual snow and ice thickness measurements

During the on-ice stations, snow depth was measured manually with a ruler stick, and sea ice thickness, freeboard, and snow depth were measured from drill holes.

Table 1. Deployments of autonomous devices

Identifier	IMEI	Type	Location	Day of deployment
2023S126	300234060728940	Snow Buoy	89.98/117.23	2023-08-16
2023T112	300534063058450	Thermistor buoy / SIMBA	89.99/135.42	2023-08-16
2023S128	300234061152630	Snow Buoy	89.92/-89.32	2023-08-31
2023T111	300534063058460	Thermistor buoy / SIMBA	89.92/-89.32	2023-08-31

3.2.4 Ice core drilling

During the ice stations, several ice cores were drilled to determine the distribution of temperature, salinity, and strength in the ice over the thickness. The temperature was measured immediately after taking the cores. The cores were then cut into 10 cm long sections and brought on board in appropriate transport containers. There they were allowed to melt to determine the salinity in the melt water. Separate cores were used to measure the strength. These were cut into 12 cm long sections and then pressed with a special hydraulic compression test apparatus and the forces and deformations that occurred were measured.
The exact number of cores taken and their utilization can be seen in the following list:

- 2023-08-15 / Station #1: temperature and salinity (3 cores)
- 2023-08-16 / Station #2: temperature and salinity (2 cores), strength (1 core)
- 2023-08-17 / Station #3: temperature and salinity (1 core), strength (1 core)
- 2023-08-20 / Station #4: temperature and salinity (2 cores), strength (1 core)

3.2.5 Thermal infrared scans of ship

Parallel to the temperature measurement of the ship's structure using temperature sensors, described in 3.1.5, the temperature of the ship's structure was also measured from the outside at various times using a MICRO-EPSILON thermoIMAGER TIM VGA thermal imaging camera. On the one hand, this made it possible to validate the measurement with temperature sensors. On the other hand, the thermal images were able to capture the entire temperature distribution in the outer hull structure at selected times, while the temperature sensors provide continuous but only very local data so that both measurement systems complement each other very well.

3.3 Deployments of autonomous devices on sea ice for continuous measurements

In total, four autonomous measurement platforms (buoys) were deployed at the North Pole (90°N) on 16 Aug (Cruise No CC110823) and 31 Aug 2023 (Cruise No CC260823, Table 1). On each cruise, one Snow Buoy measuring snow depth and surface atmospheric conditions, and one thermistor string sea ice mass balance buoy (type SIMBA) measuring temperature profiles of air, snow, sea ice, and ocean, were deployed. All data are made available through the data and information portal Meereisportal.de. Buoy deployment included testing of the buoys on board before deployment, drilling of holes in the ice, installation, and deployment, and complementary measurements and descriptions of the sea ice conditions and sensors.

4 Station List

Table 2. Station List

Station No.	Date 2023	Time [UTC]	Latitude [°N]	Longitude [°E]	Gear	Remarks/IDs
Habour of Longyear-byen	11.08	05:00 - 16:00	-	-	Temperature sensors / loggers	data download, installation of new sensors, restart of measurements
Sailing in open water	08-12	16:08			SIMS	Calibration of SIMS over open water
Sailing in open water	08-12	16:41	81.18	21.46	Reolink Camera (facing backward)	Start of continuous visual recordings
Sailing in open water	08-12	16:50	81.18	21.460	SIMS	Start of continuous measurements of sea ice thickness
Sailing in open water	08-12	17:27	81.27	22.09	DMU	Start of continuous measurements of ship motions
Entry of pack ice	08-12	20:27	81.82	24.50	–	Visual ice observations
Sailing in ice	08-13	7:01	83.41	29.78	Mavic 3 drone	Grid survey, 20230813_12
Sailing in ice	08-13	11:54	83.84	33.54	SIMS	Calibration of SIMS over open water
Sailing in ice	08-13	16:47	84.48	37.23	Reolink Camera	Start of continuous visual recordings
Sailing in ice	08-13	16:50	84.48	37.30	Scanning laser	Start of continuous measurements of sea ice roughness
Sailing in ice	08-13	19:02	84.58	40.00	Mavic 3 drone	Grid survey, 20230813_3
Sailing in ice	08-13	19:26	84.58	40.00	Mavic 3 drone	Scale flight, 20230813_4
Sailing in ice	08-14	11:00	85.35	59.76	Thermal camera	Thermographic measurements on the LCC and Polarstern
Sailing in ice	08-14	17:36	85.77	51.71	Mavic 3 drone	Grid survey, 20230814_1
Station 1	08-15	8:30 - 10:00	87.56	49.25	coring system, auger drill	coring: temperature, salinity
Station 1	08-15	9:12	87.56	49.22	GEM	Ice thickness survey, 20230815-survey

Table 2. Station List

Station No.	Date 2023	Time [UTC]	Latitude [°N]	Longitude [°E]	Gear	Remarks/IDs
Station 1	08-15	10:01	87.55	49.19	Mavic 3 drone	Grid survey, 20230815_1
Station 1	08-15	10:20	87.55	49.19	Manual snow and ice thickness measure-ments	Drilling next/with coring, ruler measurements of snow thickness
Station 1	08-15	10:22	87.55	49.22	GEM	Evaluation of SIMS, 20230815-survey
Sailing in ice	08-15	18:45	88.15	45.03	Mavic 3 drone	Grid survey, 20230815_2
Sailing in ice	08-15	19:10	88.15	45.03	Mavic 3 drone	Stationary flight, 20230815_3
Sailing in ice	08-16	7:11	89.69	56.94	Mavic 3 drone	Grid flight, 20230816_1
Station 2	08-16	13:00 - 15:30	89.99	129.31	coring system, auger drill, compression test apparatus	coring: temperature, salinity, strength
Station 2	08-16	13:05	89.98	117.23	SIMBA buoy	Deployment of buoy
Station 2	08-16	14:15	89.99	135.42	Snow Buoy	Deployment of buoy
Station 2	08-16	16:10	89.98	111.74	Mavic 3 drone	Grid flight, 20230816_2
Station 2	08-16	16:33	89.98	111.74	Mavic 3 drone	Stationary flight, 20230816_3
Station 2	08-16	17:06	89.98	111.68	GEM	Evaluation of SIMS, GEM logger failed, 20230816-survey
Station 2	08-16	16:00	89.98	111.74	Manual ice thickness measure-ments	Evaluation of SIMS
Station 3	08-17	09:34	89.99	34.75	GEM	Ice thickness survey + SIMS Evaluation, 20230817_1-survey

Table 2. Station List

Station No.	Date 2023	Time [UTC]	Latitude [°N]	Longitude [°E]	Gear	Remarks/IDs
Station 3	08-17	10:00	89.99	34.75	Manual ice thickness measure-ments	Evaluation of SIMS
Station 3	08-17	10:00 - 11:00	89.99	34.75	Thermal camera	Thermographic measurements on the LCC
Station 3	08-17	10:21	89.99	34.75	GEM	Calibration, 20230817_2-cal
Station 3	08-17	14:30 - 16:00	89.98	1.18	coring system, auger drill, compression test apparatus	coring: temperature, salinity, strength
Station 3	08-17	17:47	89.99	25.35	SIMS	Calibration over sea ice
Sailing in ice	08-18	15:45	87.76	49.97	Mavic 3 drone	Grid survey, 20230818_1
Sailing in ice	08-18	19:34	87.02	49.31	Mavic 3 drone	Grid survey, 20230818_2
Sailing in ice	08-19	9:14	85.49	44.35	Mavic 3 drone	Grid survey, 20230819_1
Station 4	08-20	7:00 - 9:00	82.81	27.84	coring system, auger drill, compression test apparatus	coring: temperature, salinity, strength
Station 4	08-20	07:33	82.80	27.91	GEM	Ice thickness survey, 20230020-survey
Station 4	08-20	10:42	82.81	27.90	Mavic 3 drone	Single shots, 20230820
Leaving the ice pack	08-20	20:10	81.62	21.37	–	Visual observation
Sailing in glacier fjord	08-21	6:24	79.98	13.65	Reolink Camera	Stop of continuous visual recordings
Sailing in glacier fjord	08-21	6:24	79.98	13.67	Scanning laser	Stop of continuous measurements of sea ice roughness

Table 2. Station List

Station No.	Date 2023	Time [UTC]	Latitude [°N]	Longitude [°E]	Gear	Remarks/IDs
Sailing in glacier fjord	08-21	07:00	79.85	14.07	DMU	Stop of continuous measurements of ship motions
Sailing in glacier fjord	08-21	11:47	79.61	12.74	CTD	Conductivity measurements for SIMS calibration
Sailing in glacier fjord	08-21	11:55	79.61	12.74	Manual water sample	Conductivity measurements for SIMS calibration
Sailing in glacier fjord	08-21	14:17	79.61	12.73	SIMS	Stop of continuous measurements of sea ice thickness
Sailing in glacier fjord	08-21	14:24	79.61	12.73	SIMS	Calibration over open water
Sailing in glacier fjord	08-21	21:47	79.75	12.12	Reolink Camera (facing backward)	Stop of continuous visual recordings
Sailing in glacier fjord	08-23	11:30	79.56	10.98	Thermal camera	Thermographic measurements on the LCC
Habour of Longyear-byen	08-26	08:00 - 10:00	-	-	Temperature sensors / loggers	data download

5 Preliminary Results

5.1 Underway measurements

5.1.1 Sea ice total thickness, type, and surface roughness

Figure 5 displays the preliminary total (snow+ice) thickness time series measured by the SIMS. While the general spread and distribution of thickness measurements seem plausible, a quick comparison with in-situ measurements shows that the SIMS overestimates the total thickness. In addition, on 2023-08-13 5:10 UTC, the thickness dropped unexplained by 1.5 m. A calibration on 2023-08-13 could re-establish reasonable thickness measurements, but this event requires further investigation. We will use the in-situ measurements and the additional calibrations to post-process the SIMS total thickness time series. The visual images from the front camera are an additional tool for quality-controlling the SIMS. Figure 6 shows the view of the front camera that monitors the ice measured by the SIMS and the surrounding ice. On the visual images, we can distinguish between open water and different ice types, e.g., melt-ponds or ridges. By selecting times when the camera indicates open water below the SIMS, we can create an additional reference dataset. Based on those extensive opportunities for quality control, we can update the SIMS routines to improve its performance.

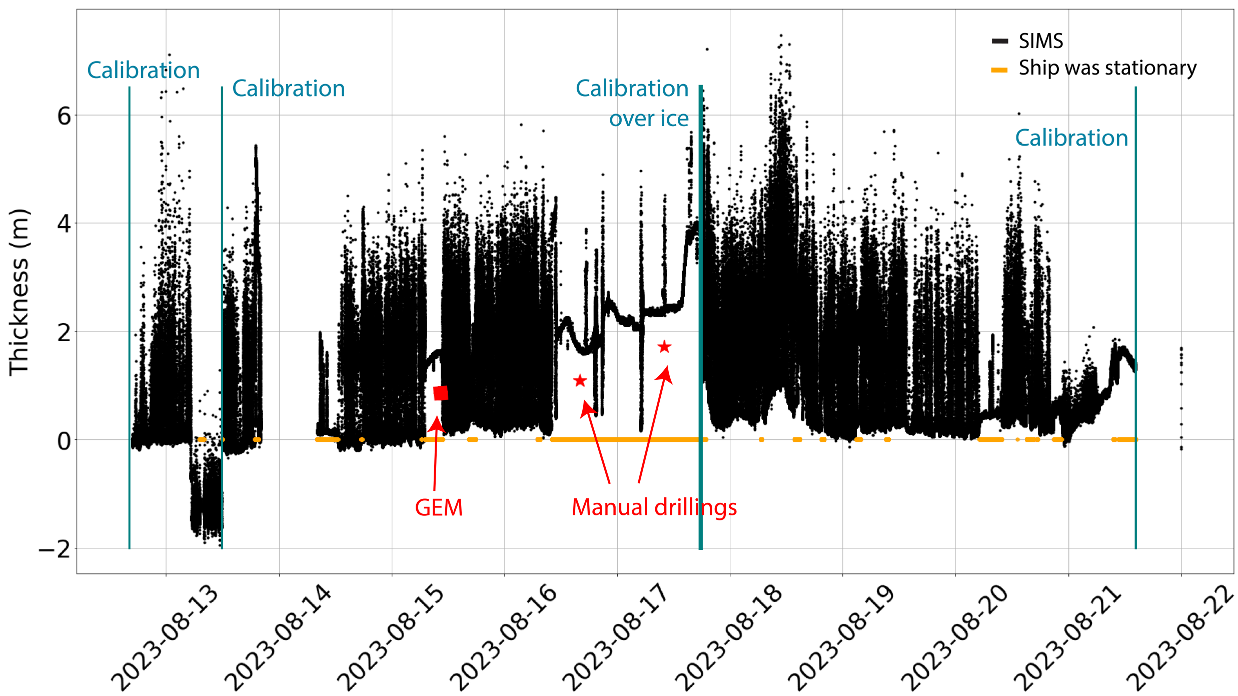

Figure 5. Preliminary SIMS sea ice thickness time series with evaluation datasets that will be used for post-calibration and post-processing.

In addition to total thickness and sea ice type, we also recorded sea ice roughness and topography with a scanning laser. Figure 8 shows an example of a laser scan where the colors indicate the backscatter intensity over sea ice (in blue and green colors) and open water (black, no return). The backscatter intensity can be interpreted as a proxy of surface roughness with brighter colors indicating rougher ice.

For synchronizing all measurements, we performed a time alignment of the underway measurements. Between the laser scanner & front camera system ("zero") and the SIMS there is an offset of: -00:00:05 (hh:mm:ss). Between the laser scanner & front camera system ("zero") and the back camera is an offset of: + 02:00:05 (hh:mm:ss).

5.1.2 DMU

Due to problems with the data acquisition system, it was not possible to continuously measure the ship's movements with the DMU. Further analyses must show whether and to what extent existing individual measurement segments can be meaningfully evaluated.

5.1.3 Temperature loggers

First, preliminary results of the temperature measurements on the ship structure are presented taking the measurements in the wet lab (WL) and the Garbage Treatment Room (GTR) from 2023-08-15 to 2023-08-17 as an example. The temperature distribution in the outer shell as well as the ambient temperature in both rooms are shown in in Figure 9 and Figure 10. While the temperatures of the outer shell in both rooms under consideration show very similar values until 2023-08-16 at 6:00 UTC, there is a significant increase in temperature thereafter. In the wet lab, the temperature rises to almost 56°C and in the Garbage Treatment Room to 40°C. These temperatures cannot be caused by environmental influences, but must have been caused by one or more heat sources in the ship, that need to be identified. In comparison, the ambient air temperatures in both rooms vary only slightly.

Figure 6. View of the front camera

Figure 7. View of the backward facing camera 16/08/2023 01:17:45 UTC

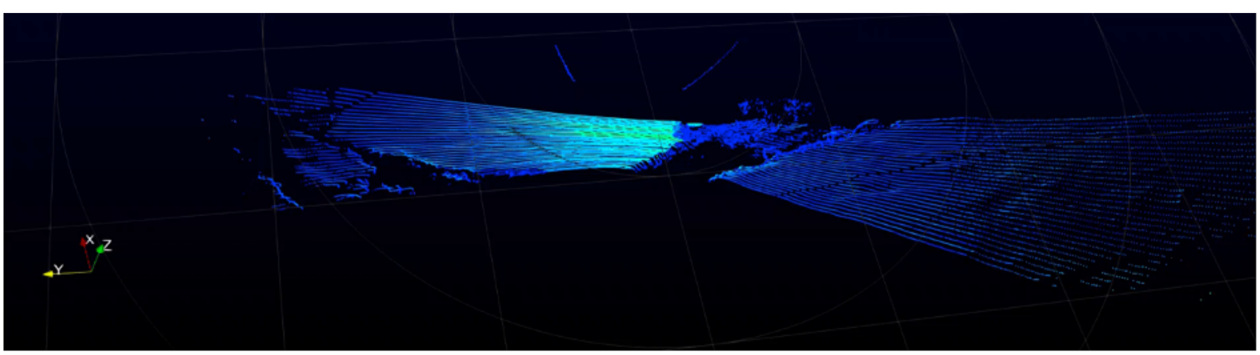

Figure 8. Backscatter intensity of scanning laser over sea ice (blue and green colors) and open water (dark, no return).

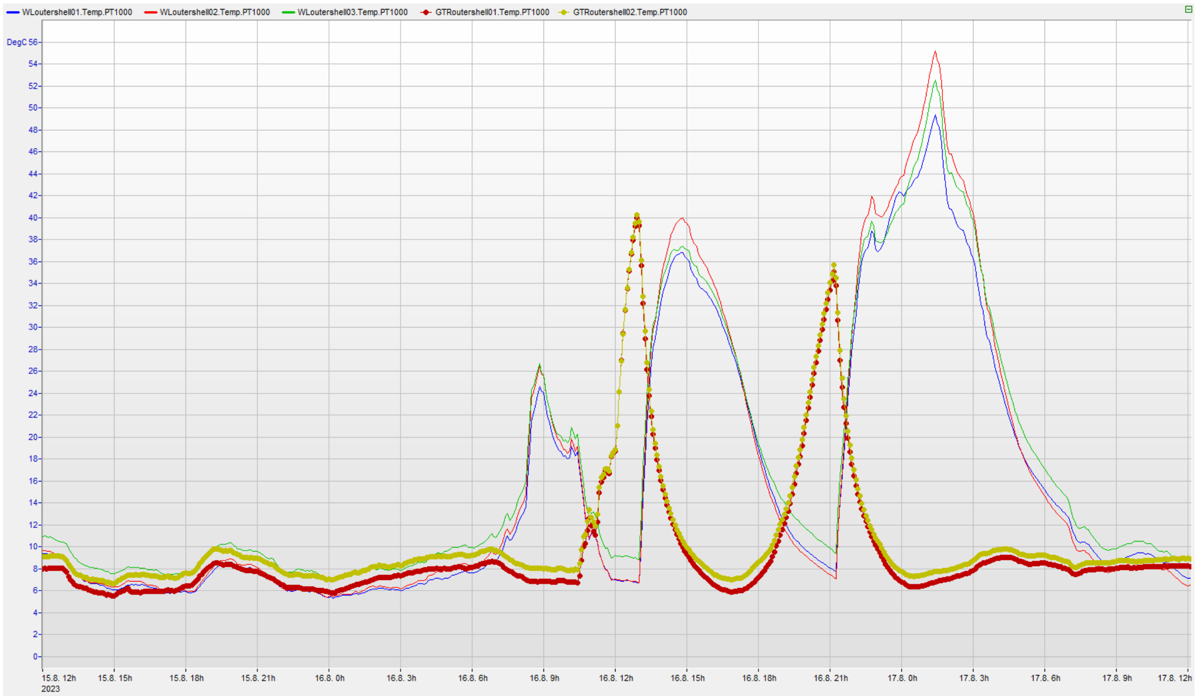

Figure 9. Comparison of the outer shell temperature distribution of the WetLab (WL) and the Garbage Treatment Room (GTR).

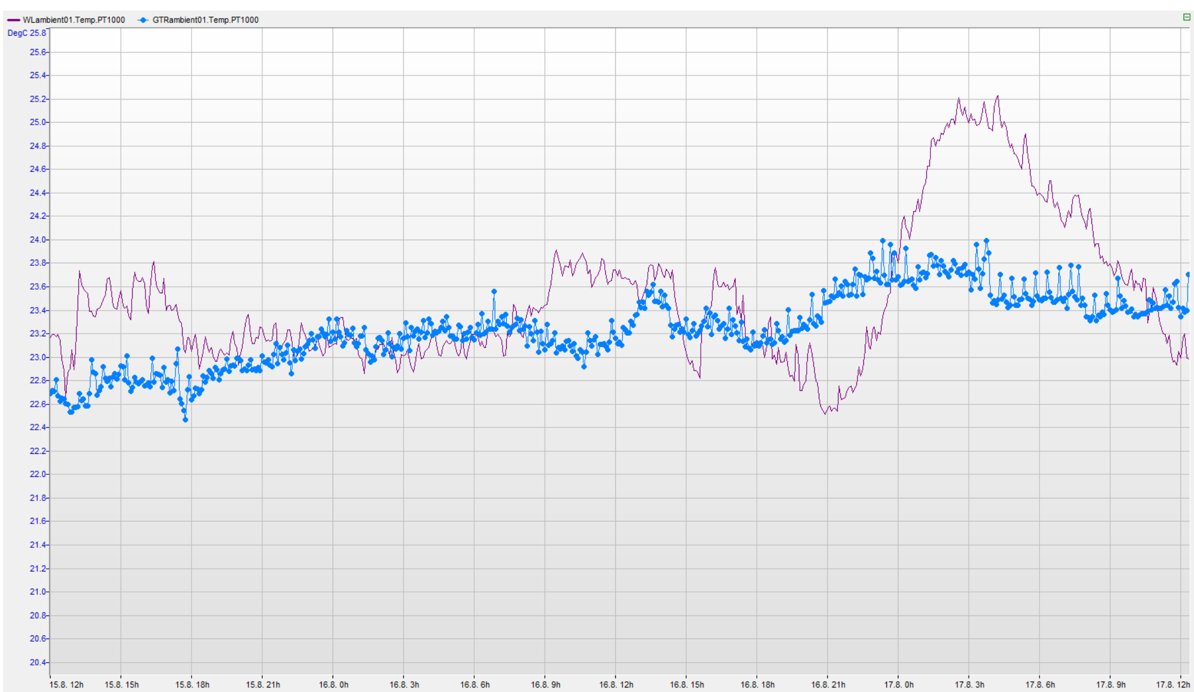

Figure 10. Comparison of the ambient temperature in the WetLab (WL) and the Garbage Treatment Room (GTR).

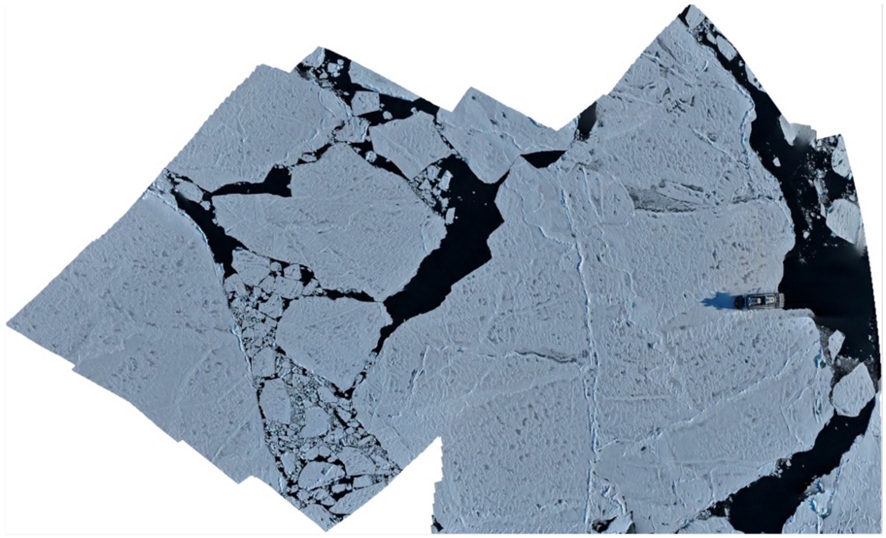

Figure 11. Orthomosaic from drone images captured on 2023-08-16 (ID: 2023-08-16_02). The extent of the orthomosaic is approx. 2.6 x 1.2 km with a pixel size of 10 cm.

5.2 Station work on sea ice and from the vessel

5.2.1 Sea ice surface properties and roughness based on aerial photographs: Mavic 3 drone flights

The geographic distribution of all 14 drone flights is illustrated in Figure 1. Variable weather conditions resulted in different flight altitudes (20-450 meters) and duration (approximately 5-20 minutes). Figure 11 displays the orthomosaic captured on 2023-08-16 at the North Pole. The orthomosaic consists of 800 single photographs covering an area of 3.12 km^2 with a spatial resolution of 10 cm. The orthomosaics provides an aerial overview of the surveyed and the surrounding ice floes of ice station 2, the distribution of ridges, leads, and level ice. Refrozen and partly snow-covered melt ponds are still well visible.
Figure 12 compiles a series of orthomosaics, consistently sized, spanning from 83-90°N. This composite offers valuable insights into the evolving characteristics of sea ice surface properties, e.g., melt ponds from the sea ice edge to the central pack ice.

5.2.2 Sea ice thickness - GEM

We present preliminary results from the ice station #1 on 2023-08-15. The mean ice thickness was 2.6±1.2 m with a minimum and maximum thickness of 0.75 m and 6.1 m. The sea ice thickness distribution (a histogram of all measurements) is shown in Figure 13. The distribution is multi-modal with the dominant mode at 1.6-1.8 m. Figure 5 shows the GEM point measurements below the SIMS on August 15 together with the SIMS ice thickness retrievals.

5.2.3 Coring

The measured temperature and salinity distribution of ice cores #1 and #2 and the distribution of the compressive strength of ice core #3 measured at ice station #4 on 2023-08-20 are sown in Figure 14 and 15. The Ice cores #1 and #3 were taken at a distance of about 20 cm from each other, ice core #2 at some distance on the other side of a small ridge. The ice thickness changes significantly from 112 cm at the borehole of core #1 to 215 cm at borehole of core #2. Due to time limitations, no further ice core could be taken near the borehole of core #2 to determine the compressive strength there.

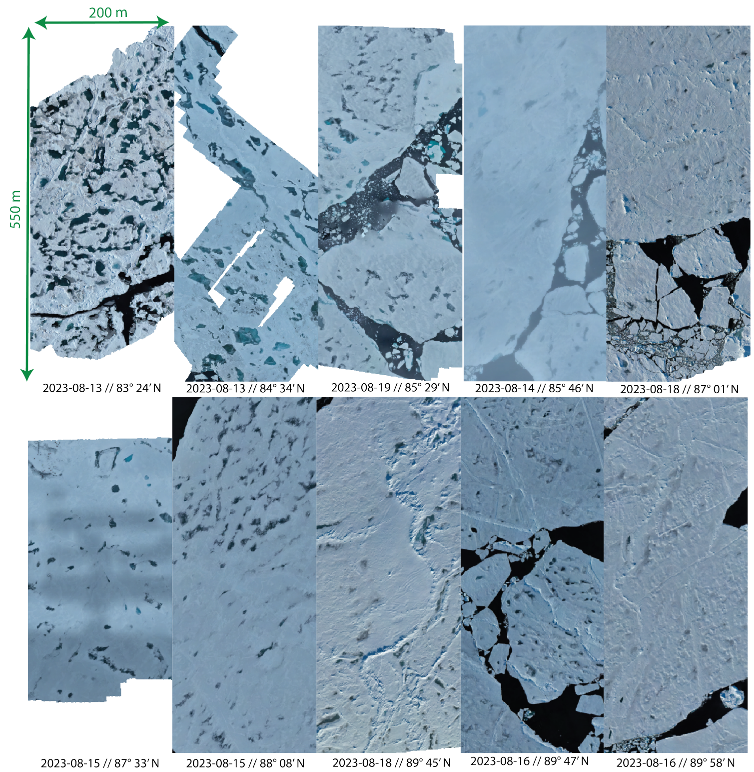

Figure 12. Series of orthomosaics covering the same area, ordered by latitude shows the evolution of sea ice surface characteristics along a transect from 83°N to 90°N.

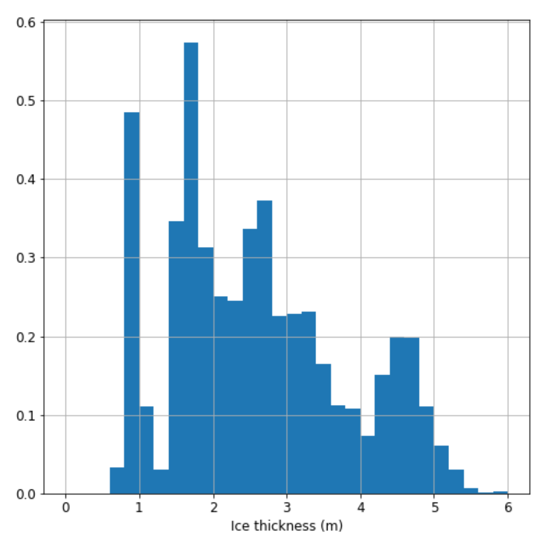

Figure 13. Sea ice thickness distribution from GEM grid survey on 2023-08-15 during Ice Station 1.

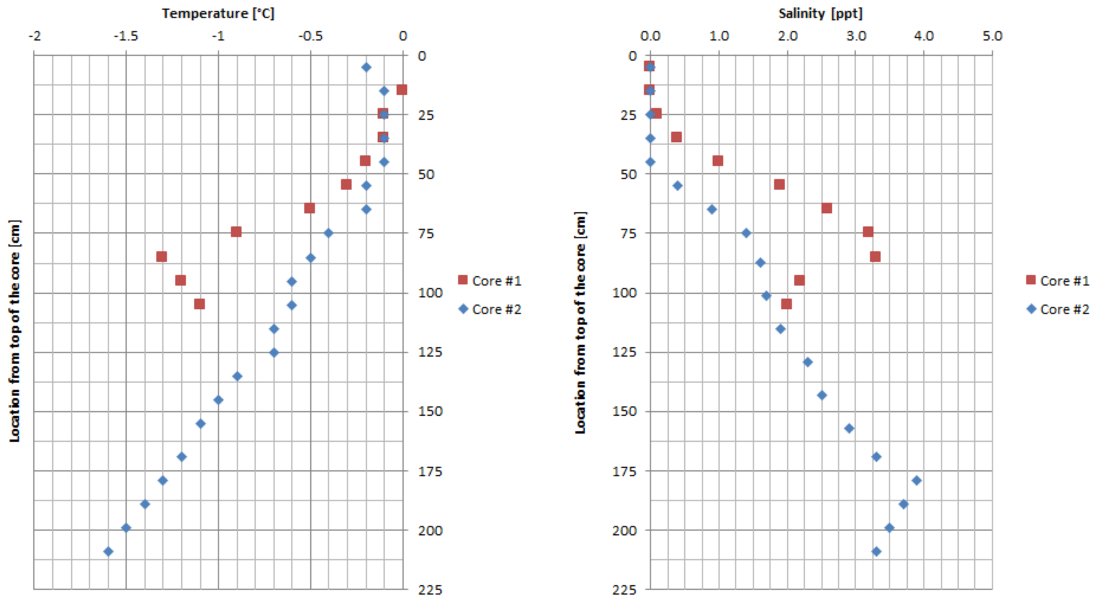

Figure 14. Temperature distribution of ice cores #1 and #2 from ice station #4

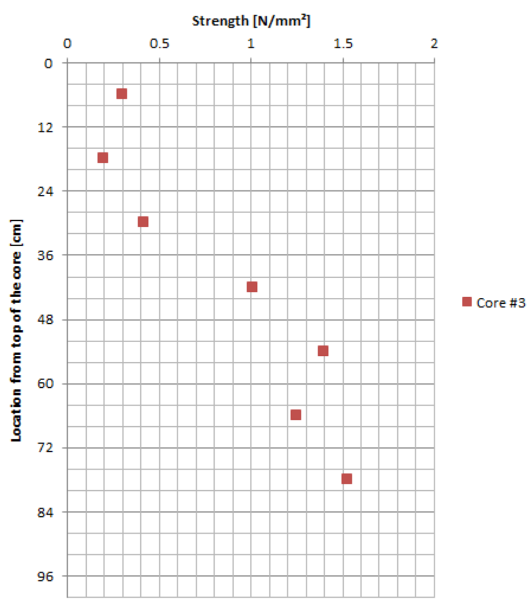

Figure 15. Compressive strength distribution of ice core #3 from ice station #4

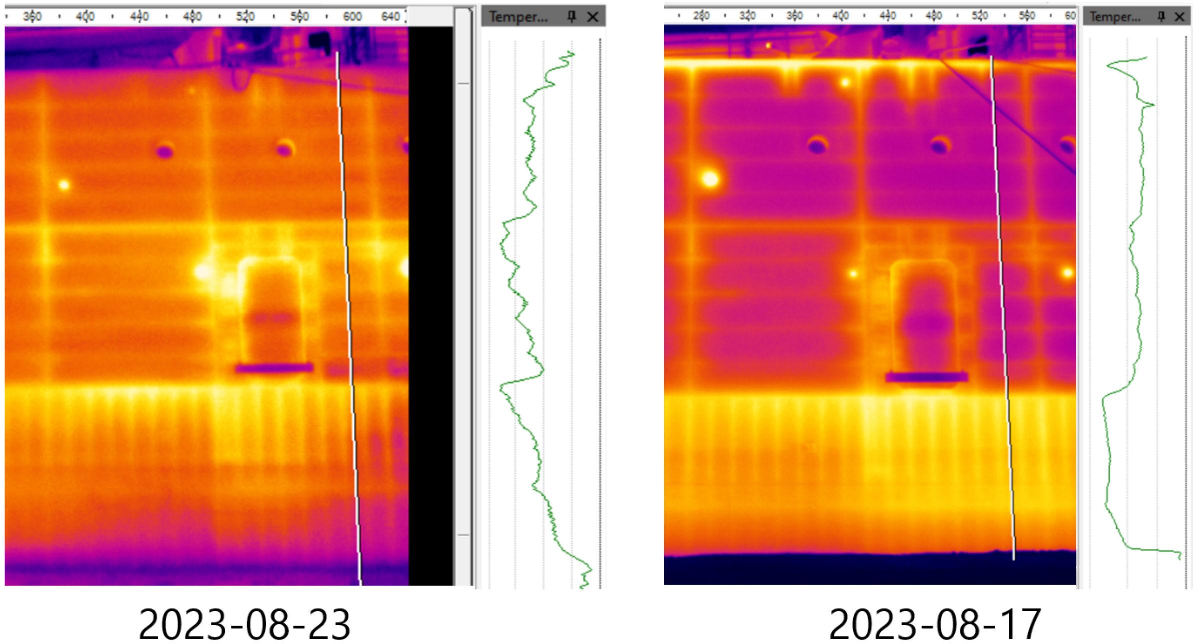

Figure 16. Exemplary, qualitative visualisation of the temperature distribution in open water (left) and in ice (right), the graph shows the temperature along the white line shown.

5.2.4 Thermal infrared scans

First, preliminary results of the thermal infrared scans are presented by means of exemplary, qualitative visualization of the temperature distribution shown in Figure 16 of the outer shell in the area of the WetLab in open water and ice. The qualitative differences are quite clearly visible. In particular, in the lower third of the structure, a drop in temperature in the open water is shown, while the temperature in the same area in the ice remains almost constant. The exact causes that lead to this behavior must now be investigated further.

5.3 Autonomous devices on sea ice for continuous measurements

Here, we present the exemplary measurements from the Snow Buoy 2023S126. We deployed the buoy on 2023-08-16 during the ice station 2 (Figure 17). In a distance of about 6 m we deployed a SIMBA buoy. In addition, there is a drone orthomosaic (Figure 11) available that characterizes the sea ice floes. Figure 18 displays a time series of measurements from the Snow Buoy. The buoy recorded an increase in surface height on 2023-08-25 most likely associated with a snowfall event. All data is available following the link: https://data.meereisportal.de/relaunch/buoy.php?buoytype=SB&region=n&buoystate=active&expedition=Charcot_2023&submit1=Anzeigen&active-tab1=method&ice-type=buoy&lang=de&timeline=buoy&active-tab2=buoy&showMaps=y&dateRepeat=n#2023S126

6 Data and Sample Storage / Availability

After quality control and preliminary analysis, we will submit all data to the data repository Pangaea (https://www.pangaea.de/) where they will be openly accessible following the FAIR principles. All buoy data are already available from the sea ice portal: https://data.meereisportal.de/relaunch/buoy.php?buoytype=all&

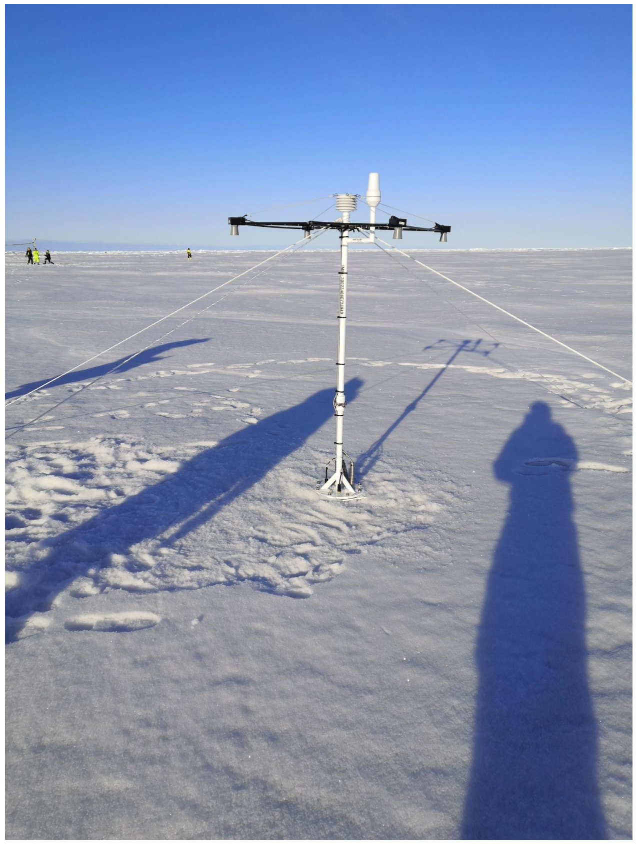

Figure 17. Snow Buoy 2023S126 deployed during ice station 2 at the North Pole on 2023-08-16.

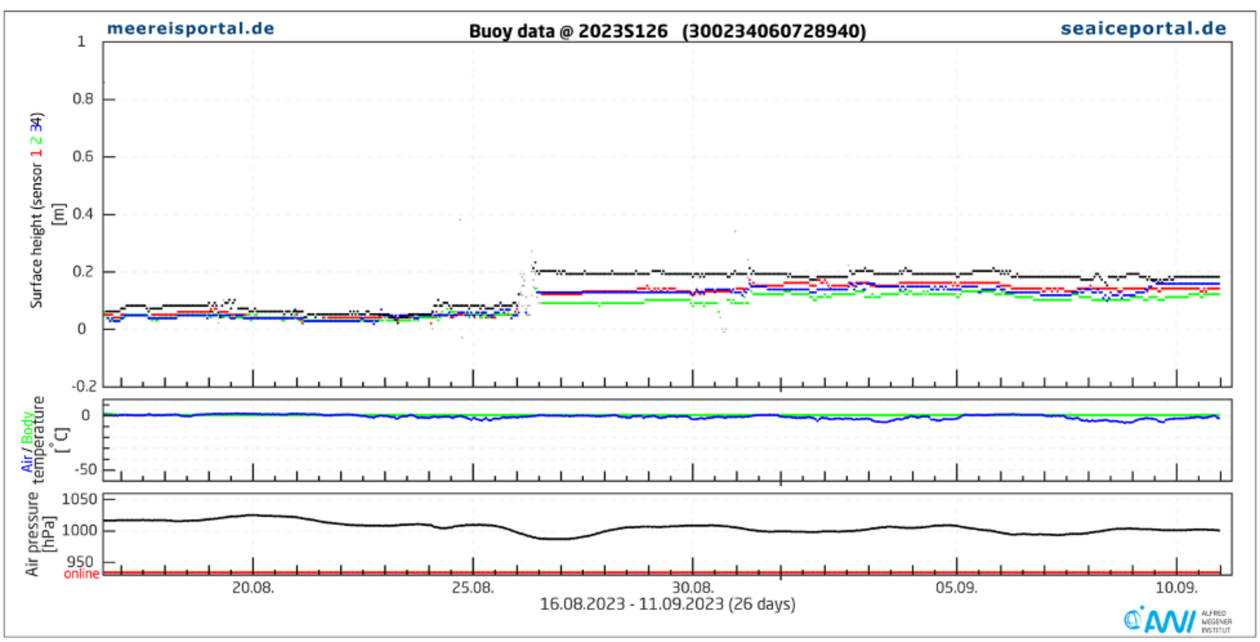

Figure 18. Data from Snow Buoy 2023S126 from 2023-08-16 to 2023-09-10.

region=n&buoystate=all&expedition=Charcot_2023&submit1=Anzeigen&active-tab1=method&ice-type=buoy&lang=de&timeline=buoy&active-tab2=buoy&showMaps=y&dateRepeat=n

7 Participants

Table 3. List of participants

No	Name	Early career (Y/N)	Gender	Affiliation	On-board tasks
1	Luisa von Albedyll	Y	F	AWI	SIMS, Scanning laser, front camera, drone flights, GEM surveys, buoy deployments, manual drilling
2	Jan M. Kubiczek	Y	M	TUHH	Back camera, dynamic motion unit, temperature loggers, thermal infrared scans, coring, temperature and salinity measurements and compressive strength tests of cores
3	Christian Haas	N	M	AWI	PI (not on board)
4	Franz von Bock und Polach	N	M	TUHH	PI (not on board)

AWI: Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
TUHH: Hamburg University of Technology, Hamburg, Germany

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