ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

Campaign report

March/April 2023

IceBird Winter 2023 Campaign

Sea ice surveys with Polar 6 from Inuvik, Eureka, Resolute Bay, Station Nord and Longyearbyen

HELMHOLTZ
ASSOCIATION

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IceBird Winter 2023 campaign

Campaign overview	
Base/Route	Inuvik / Resolute Bay / Eureka / Station Nord / Longyearbyen
Duration	March 25 – April 25, 2023
Survey hours	30 (without ferry and test flights)
Aircraft	Polar 6
Crew	Dean Emberly (chief pilot), Krish Venky (co-pilot, Inuvik only), Aron Westerbeek (co-pilot, Inuvik - Longyearbyen) Julien Lafontaine (mechanic),
Science	Cristina Sans Coll (engineer), Arttu Jutila (scientist), Esther Horvath (press officer), Thomas Krumpen (lead)

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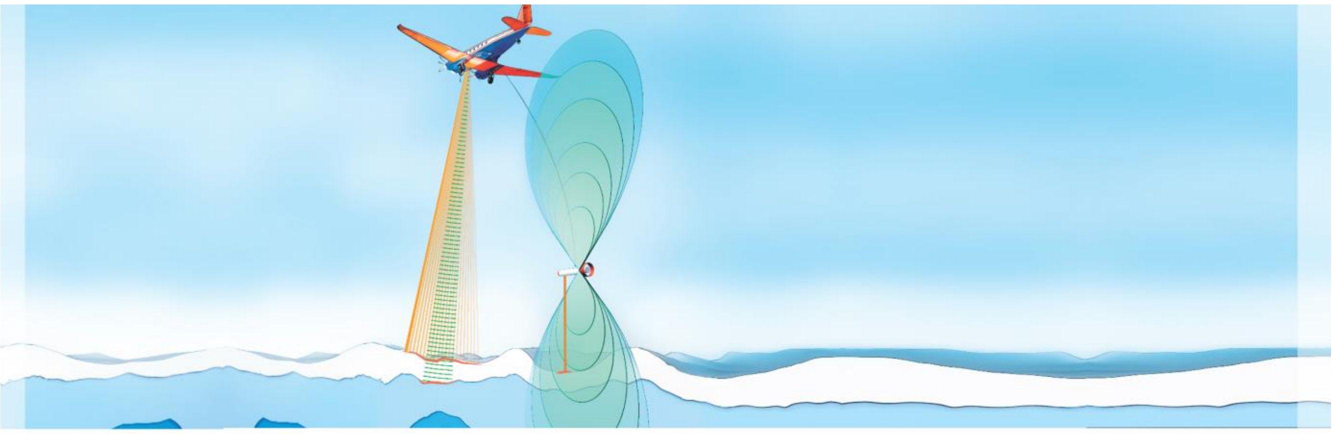

1.0 Objectives

IceBird Winter 2023 is part of a long-term sea ice observation program within the IceBird aircraft campaign series. IceBird was initiated in 2018 with the objective to ensure the long-term availability of a unique data record of direct sea-ice thickness observations to understand the role of the sea ice component for the causes and consequences of Arctic change, but is built on the heritage of airborne sea-ice thickness observations that date back to 2004. Compared to earlier airborne programs, IceBird has been enhanced with an improved sensor setup that also allows measuring snow depth on sea ice, fully collocated with sea-ice thickness and surface roughness at high resolution.

The objectives of IceBird Winter 2023 include the continued quantification of trends, the separation of variability and extreme events of sea ice thickness and its snow cover in the Western Seas of the Arctic Ocean. The continuation of airborne sea-ice observation programs fulfils the requirement of consistent and long-term observations of key climate parameters. The data will be used to improve understanding of the response of sea ice and its snow cover to the ongoing warming of the Arctic and to improve snow models. Airborne data of snow and sea-ice thickness are also critically needed for the evaluation of sea-ice remote sensing products as well as for the evolution of algorithms for current and future satellite missions. Surveys from IceBird Winter 2023 will target the validation of sea-ice freeboard and snow depth estimates from CryoSat-2, ICESat-2, Sentinel-3A/B and AltiKa altimeters.

Fig. 1: The IceBird Winter 2023 team plus Station Nord crew

2.0 Methods and Sensors

Survey flight organization and pattern

To extend the flight range of Polar 6, IceBird is designed as a lightweight campaign. Therefore, instrumentation is limited to the AEM-Bird, laser scanners, optical cameras, snow radar and radiation sensors.

Survey flights were mostly made towards one or more pre-defined points of return. The point of return and profile length are chosen according to fuel capacity, weather condition, and ice condition. Sea ice properties were documented with a photogrammetric system, a laser scanner and a snow radar. The observation of ice thickness with the AEM-Bird is limited to low flight levels (50 feet, Fig. 2).

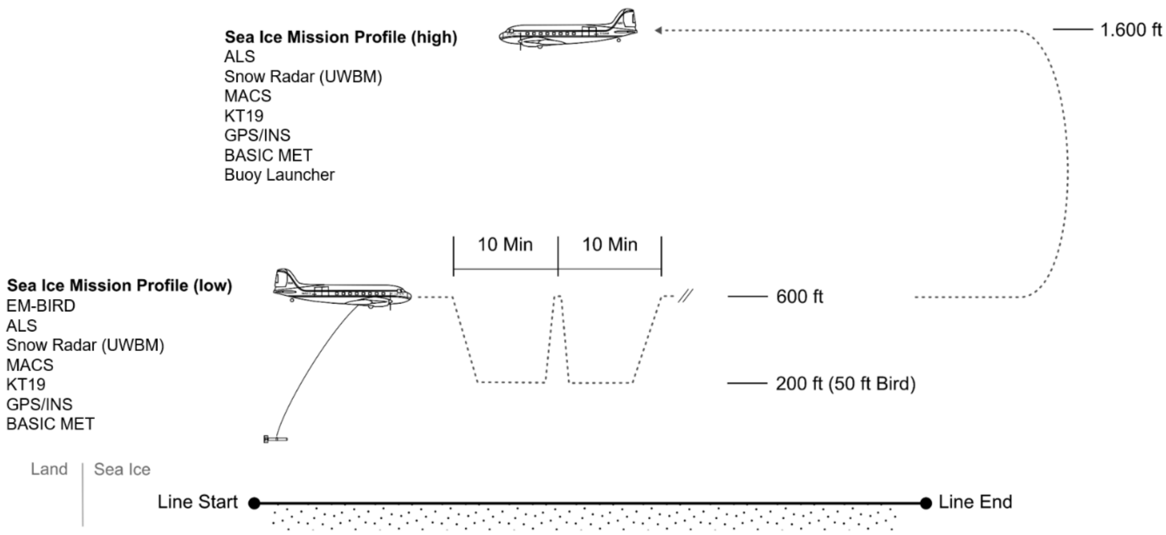

Fig. 2: Flight pattern for survey flights over sea ice.

Weather Routing and Ice Information

Weather information were obtained via SFTP from the German Weather Service (DWD). The DWD provided a tailored collection of meteograms and Ensemble Prediction System (EPS-grams, 120h ahead; initialized 00UTC and 12UTC, available with 6-9h delay, Fig. 3) for different key locations, data from weather satellites as well as forecast maps for cloud cover (low, medium, high), near-surface temperature, humidity, pressure and winds. All of these parameters were provided from the ECMWF forecast system, most also from the ICON system, and some in addition from the GFS system. Data download was handled in near-real time by a python script written by Valentin Ludwig. The source code is made available for future campaigns via a Git repository (https://gitlab.awi.de/vludwig/ICEBIRD).

Near-real time sea ice information (sea ice concentration, drift forecasts and Sentinel-1 imagery, Fig. 4) were obtained via the https://icysea.app/ developed by Drift+Noise Polar Services.

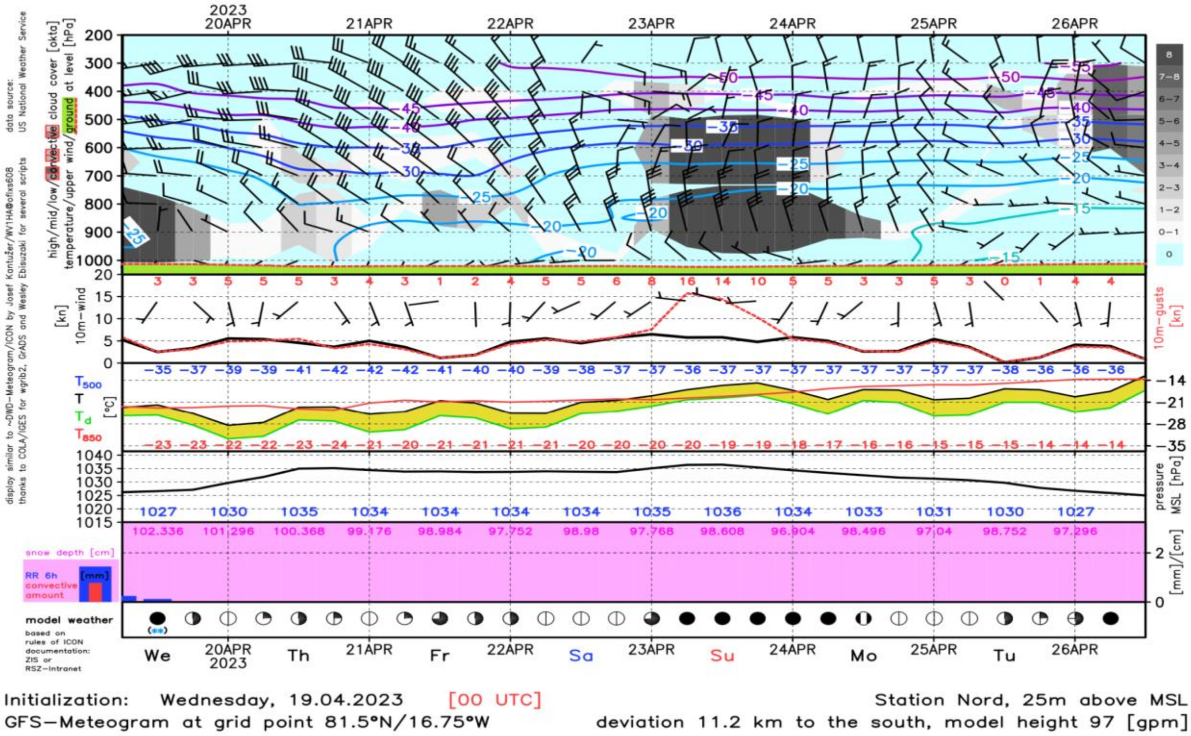

Fig. 3: Example for a GFS meteogram provided by the DWD for Station Nord on April 19, 2023.

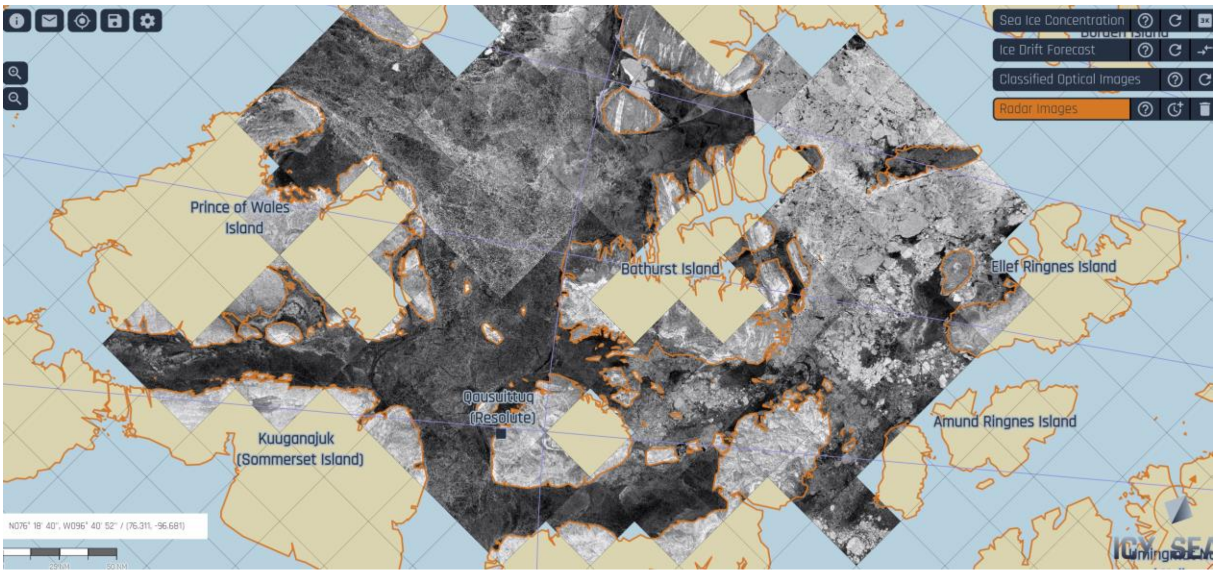

Fig. 4: Screenshot of the IcySea.app providing sea ice concentration, drift forecast and high resolution SAR images (example for 10th April 2023)

Instrumentation

The **Airborne electromagnetic (AEM) Bird** is a sensor system that is towed by the research aircraft Polar-5 or Polar-6 at 20 m above the ice surface. The EM sensor utilizes the contrast of electrical conductivity between sea water and sea ice to determine the distance of the instrument to the ice-water interface. An additional laser altimeter mounted inside the AEM-Bird provides the distance to the snow/ice surface. The difference between AEM and laser distance measurements is the ice plus snow thickness with an accuracy in the order of ±0.1 m over level sea ice. The so-retrieved thickness data enables us to determine the general thermodynamic and dynamic boundary conditions of ice formation. The most frequently occurring ice thickness, the mode of the distribution, represents level ice thickness and is the result of winter accretion and summer ablation.

The **MACS** (Modular Aerial Camera System) is a photogrammetric camera developed by DLR's Institute of Optical Sensor Systems. It consists of a computing unit and a sensor head. The sensor head is equipped with matrix array CCD/CMOS/thermal-infrared cameras and is mounted in the fuselage providing free view down. In order to fulfill respective application requirements, sensors, their geometry and spectral ranges are modified. Thus, particular conditions are considered, e. g., flying over brightly reflecting snow, acquisition of highly structured terrain or low flight altitudes without gaps of recorded ground surface. Currently the maximum continuous image acquisition rate is 4 frames per second enabling more than 60 % overlap from an altitude of 100 m (AEM-Bird surveying height).

The **snow radar** is an ultrawideband microwave radar (UWBM) for mapping near surface internal layers with very fine resolution and measuring the thickness of snow over sea ice. The system is designed to operate in frequency-modulated and continuous-wave (FMCW) mode for low-altitude measurements (500-1000 m) and stretch mode for high-altitude measurements 2500 m and above. During IceBird, the radar will only be operated in low altitude mode in both sea ice low and sea ice high mission profiles. However, 10-dB dampeners are inserted at the transmitter to avoid saturation at the low mission profile. The system specifications are given in Table 1 (Jutila et al., 2022b).

Tab. 1: Overview of snow radar (UWBM) specifications.

Parameter	**Value**
Operating Frequency	2-18 GHz
Number of Transmit Channels	2 (H-pol. and V-pol.)
Transmit Power	100 mW @ 200 ft; 1000 mW @ 1500 ft
Number of Receive Channels	2 (H-pol. and V-pol.)
Receiver Sampling Rate	125 MHz
Digitizer	14-bit A/Ds
Antenna	Dual-pol. Horn
Cross-track footprint diameter (pulse-limited)	2.6 m @ 200 ft; 7.2 m @ 1500 ft
Along-track footprint diameter (unfocussed SAR)	1.0 m @ 200 ft; 5.1 m @ 1500 ft
Range resolution (snow density 300 kg/m^3)	0.94 – 1.14 cm

The **airborne laser scanner (ALS)** model installed in Polar-6 is a Riegl VQ-580. The scanning mechanism is realised with a rotating mirror resulting in linear and parallel scan lines. Its specifications are given in Table 2 (from Riegl's VQ580 data sheet). The scanner needs to be configured for the specific flight profile and two configurations are required for the sea ice low (with AEM-Bird) and sea ice high (without AEM-Bird) flight altitudes. Its nominal settings are described in Table 3 (Jutila et al. 2022a).

Tab. 2: Overview of the airborne laser scanner (Riegl VQ-580) technical specifications

Parameter	Value
Field of View	+/- 30°
Angle Measurement Resolution	0.001°
Scan Speed (selectable)	10 – 150 lines per second
Laser Pulse Repetition Rate (selectable)	50 – 380 kHz
Minimum Range	10 m
Accuracy	25 mm
Precision	25 mm
Wavelength	near infrared (1064 nm)
Laser Class	3B

Tab. 3: Overview of the airborne laser scanner Riegl VQ-580 settings for low and high altitude mission profile

Parameter	Sea Ice Low Mission Profile *	Sea Ice High Mission Profile
Altitude AGL	600 ft	1600 ft
Ground Speed	120 kn	160 kn
Scan Mode	Line	Line
Measurement Program	300 kHz	200 kHz
Monitor Step Multiplier	36	24
MTA Zone	Mission Parameter	Mission Parameter
Line Start/Stop	60 deg	60 deg
Line Speed/Increment	150 lps	117.25 lps
Line Distance	0.4112 m	0.7020 m
Point Distance	0.2297 m	0.7018 m
Swath Width	211.17 m	563.12 m
Point Density	10.59 pts/m^3	2.03 pts/m^3
Max Range	211.173 m	563.124 m

* 600 ft is maximum altitude during AEM-Bird calibration procedure, nominal survey altitude is 200 ft AGL with smaller swath width and higher across track point density.

3.0 Survey overview

Sea ice extent, weather conditions and flight activities

The IceBird Winter campaign started in Inuvik on 25 March and ended in Longyearbyen on 22 April. The average Arctic sea ice extent on 19 April 2023 (at the end of the campaign) was 14.02 million square kilometres, which is the fifth lowest value observed by satellites (Fig. 5).

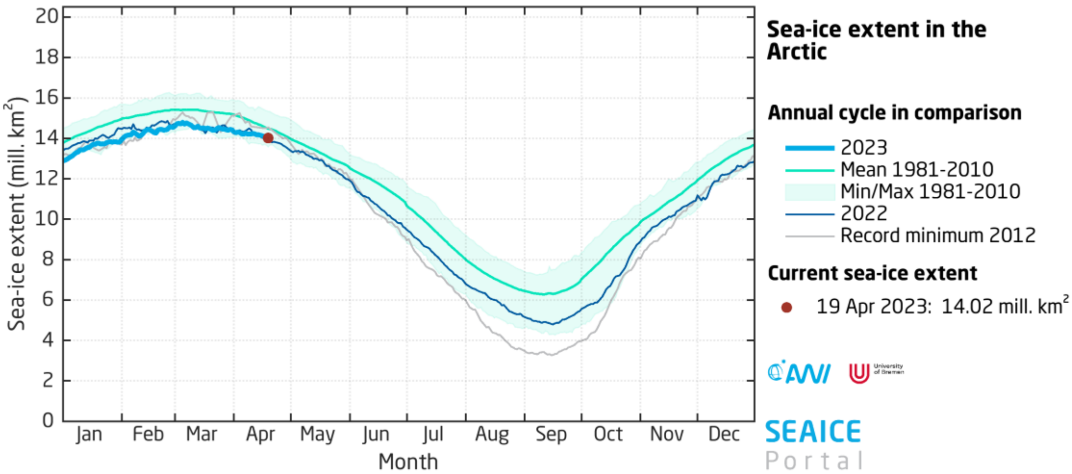

Fig. 5: Sea ice extent in the Arctic on 19 April 2023 (source: Meereisportal.de)

The first part of the campaign was characterised by mostly good weather conditions (Inuvik and Resolute Bay), which, however, could only be used to a limited extent for survey flights due to technical problems and maintenance work on the aircraft. At the end of the stay in Inuvik, however, a flight over sea ice of various ages and a mapping flight in the Trail Valley Creek were successfully completed. After arriving in Resolute Bay, another survey flight was made in Penny Strait. However, the following day's flight resulted in irreparable damage to the EM system. As the DLR camera system also failed, subsequent flight activities were limited to the use of the laser scanner and snow radar. On arrival at Eureka, the weather conditions became more adverse: poor visibility or strong winds led to several days on the ground. Nevertheless, a measurement flight over sea ice was completed shortly after reaching Eureka. On arrival in Greenland, work was hampered by the passage of several low-pressure systems in the Fram Strait, some of which brought heavy snowfall to Station Nord. A cloud-free corridor that developed north of Greenland during the last two days of the campaign and moved slowly eastwards made two final flights possible: one north of Alert as well as one north of Station Nord and in parts of the Fram Strait. On 21 April, the transit flight to Longyearbyen took place.

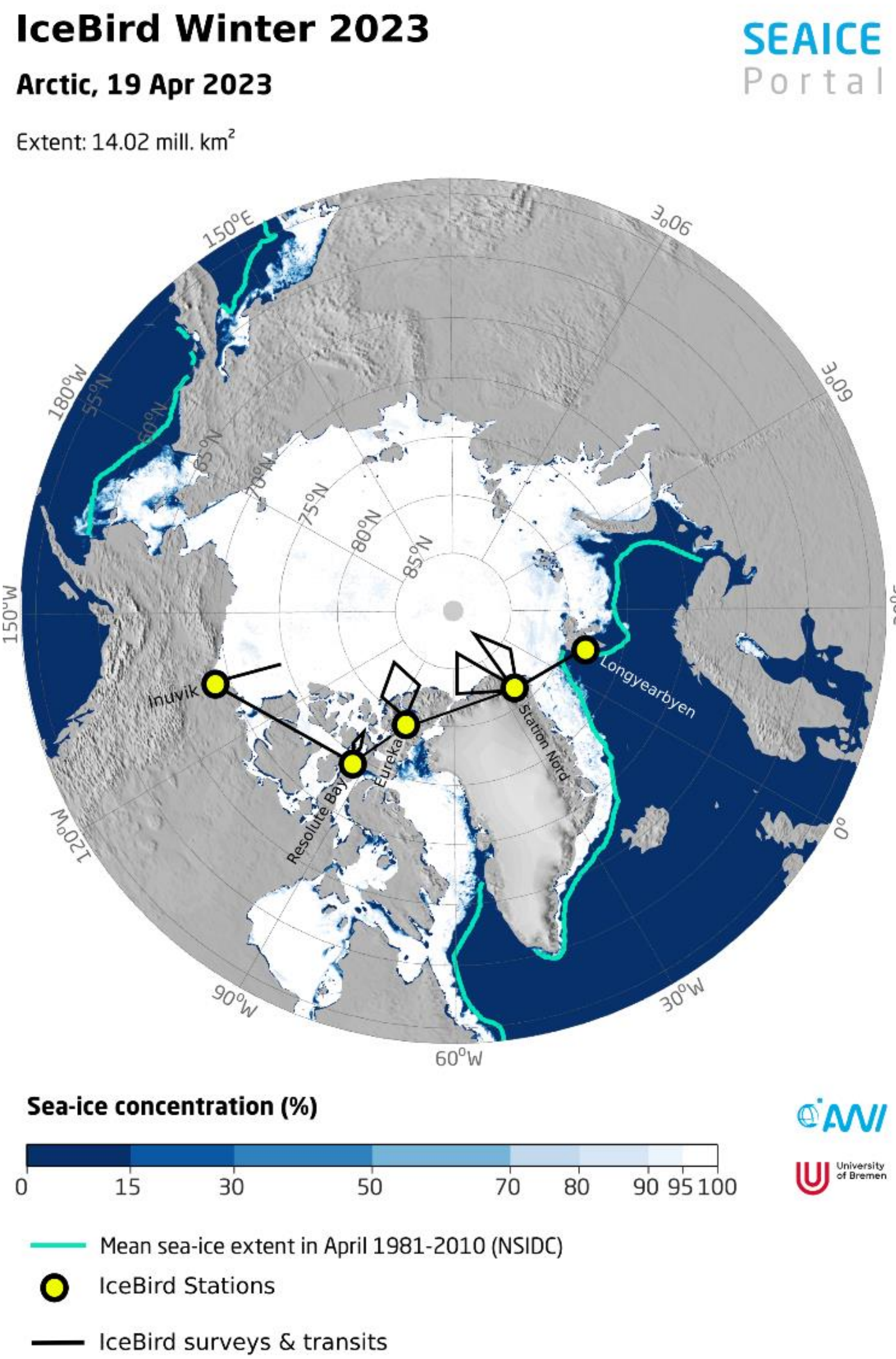

Fig. 6: IceBird surveys and transits between stations. Background: Sea ice extent on April 19, 2023.

Tab. 4: Overview of different survey and ferry flights carried out between March 23 and April 23, 2023. For survey flights, the list of active sensors is provided.

Sensor Codes	
AEM	Airborne Electromagnetic Sensor (EM-Bird)
MACS	MACS DLR Camera System (RGB/NIR/TIR)
SR	Snow Radar
LS	Laserscanner, Riegl (VQ580)
CA	CALIB Buoy Deployment

	Schedule				
	Date	**Activity**	**Route**	**Flight time**	**Active sensors**
1	Mar 23, 2023	Ferry flight	EDDW-EGPC-BIKF	7.4	None
2	Mar 24, 2023	Ferry flight	BIKF-BGFS-CYFB	7.7	None
3	Mar 25, 2023	Ferry flight	CYFB-CYCB-CYEV	8.3	None
4	Mar 26, 2023	Weather / Maintenance / Administrative issues			
5	Mar 27, 2023	Weather / Maintenance / Administrative issues	CYEV-CYEV	1.7	AEM, SR, LS
6	Mar 28, 2023	Weather / Maintenance / Administrative issues			
7	Mar 29, 2023	Weather / Maintenance / Administrative issues			
8	Mar 30, 2023	Weather / Maintenance / Administrative issues	CYEV-CYEV	0.4	
9	Mar 31, 2023	Survey flight	CYEV-CYEV	5.3	AEM, SR, LS
10	Apr 01, 2023	Weather / Maintenance / Administrative issues			
11	Apr 02, 2023	Survey flight	CYEV-CYEV	4.7	SR, LS, MACS
12	Apr 03, 2023	Ferry flight	CYEV-CYRB	5	None
13	Apr 04, 2023	Survey flight	CYRB-CYRB	3	AEM, SR, LS
14	Apr 05, 2023	Survey flight	CYRB-CYRB	1.3	AEM (touch-down), SR, LS
15	Apr 06, 2023	Weather / Maintenance / Administrative issues			None
16	Apr 07, 2023	Ferry flight	CYRB-CYEU	2.4	None
17	Apr 08, 2023	Survey flight	CYEU-CYEU	4.4	SR, LS
18	Apr 09, 2023	Weather / Maintenance / Administrative issues			None
19	Apr 10, 2023	Weather / Maintenance / Administrative issues			None
20	Apr 11, 2023	Weather / Maintenance / Administrative issues			None
21	Apr 12, 2023	Weather / Maintenance / Administrative issues			None
22	Apr 13, 2023	Weather / Maintenance / Administrative issues			None
23	Apr 14, 2023	Ferry flight	CYEU-BGNO	3.6	None
24	Apr 15, 2023	Weather / Maintenance / Administrative issues			None
25	Apr 16, 2023	Weather / Maintenance / Administrative issues			None
26	Apr 17, 2023	Weather / Maintenance / Administrative issues			None
27	Apr 18, 2023	Weather / Maintenance / Administrative issues			None
28	Apr 19, 2023	Survey flight	BGNO-BGNO	5.5	SR, LS
29	Apr 20, 2023	Survey flight	BGNO-BGNO	5.8	SR, LS
30	Apr 21, 2023	Ferry flight	BGNO-ENSB	3.3	None
31	Apr 22, 2023	Weather / Maintenance / Administrative issues			None
32	Apr 23, 2023	Weather / Maintenance / Administrative issues			None

Total flight hours	**69.8**
Ferry time plus testing	39.8
Survey time	30

4.0 IceBird Winter Photo and Video Documentary

Photographer Esther Horvath participated in the IceBird Winter 2023 campaign with the main goal to highlight the scientific work of the AWI, to continue collecting long-term video and photo material of sea ice thickness and snow measurements, and to raise public awareness about the changes of sea ice in the Arctic. The photo documentation focused on scientific activities in the aircraft, operations with Polar 6 and life at the stations. During the campaign and active social media outreach has been conducted with a total of 360,997 engagements on Instagram (stories, posts and reels) both @awiexpedition and @estherhorvath accounts. With 43,956 views, the IceBird short video had the highest engagement. (More postings will follow.) National Geographic is planning to publish a short video documentary about IceBird on NatGeo Instagram, which has 273 million followers, and the Women of Arctic Science portrait project in print and online, including Cristina Sans Coll's portrait during the campaign.

A photo story is being discussed for publication in Stern Magazine, Popular Science and National Geographic.

5.0 Preliminary Results

Below we briefly summarize results from the AEM-Bird surveys that were made from Inuvik and Resolute Bay. Hereafter, no AEM-Bird surveys were performed, since the system got damaged on a flight on 5th April.

A comparison of the survey flight made north of Inuvik on March 31st with previous winter measurements in the region (see Fig. 7a) shows only a slight decrease in modal and mean ice thickness (Fig. 7b and c). The negative (non-significant) trend is due to the increasing proportion of FYI in the study area. This is likely a consequence of intensified polynya activity in late winter. The thickness of MYI further north does not decrease for the period 2006 - 2023 (not shown).

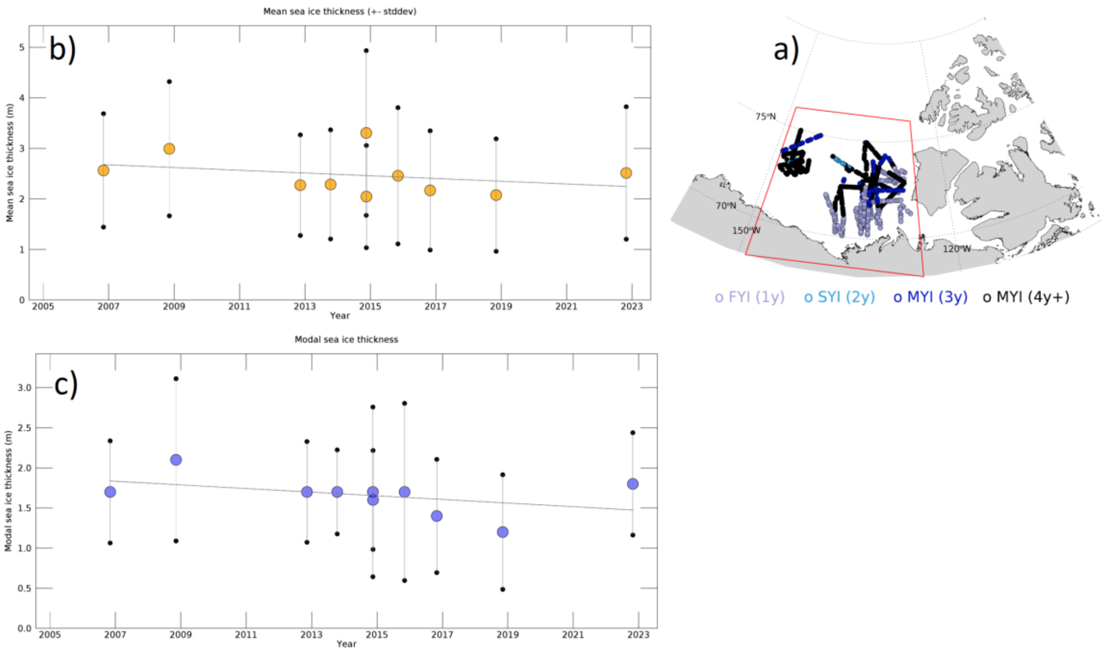

Fig. 7: a) AEM-Bird sea ice thickness surveys carried out in the area north of Inuvik (red box) between 2006 and 2023. Color coding corresponds to the age of surveyed ice (source IceTrack). b) provides the mean thickness +- Stdev, c) shows the modal ice thickness +- Stdev.

Aims of the survey flight in Penny Strait (near Resolute Bay) was to investigate small-scale variability in ice and snow thickness and interaction with the ocean and atmosphere. In Penny Strait, a transect line was flown across zones of different ice: FYI and MYI, which is locally formed, as well as MYI, which enters the Canadian archipelago from the Arctic Ocean. The flight completed on 4 April from Penny Strait covers these different zones (see Fig. 8, right). The flight begins over MYI ice (some of which is locally formed from FYI), then passes over FYI zones with thinner ice, and in the north covers MYI originating from the Arctic Ocean. In the narrows between the islands (Penny Strait), where the ocean currents are particularly strong, zones of thinner ice are visible, which can probably be explained by the locally increased heat flux from the ocean to the surface.

Subsequent work will compare sea ice surveys from 2023 AEM-Bird to surveys from April and May 2011 and 2015 (Haas and Howell, 2015). In addition, the flights will complement the IceBird Canada campaign planned for next winter (PI Christian Haas).

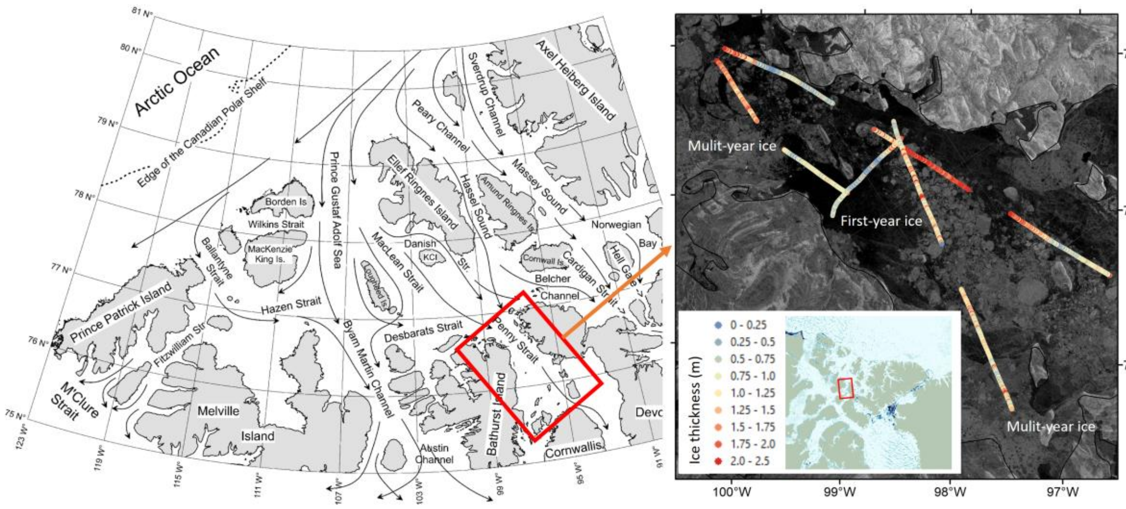

Fig 8: Left: The northern part of the Canadian polar shelf, its principal geographic features and the schematic pattern of sea-ice movement across it (adopted from Melling, 2022). The red box indicates the area for the survey on April 4th (Penny Strait). Right: Close-up of the survey area with AEM-Bird thickness measurements plotted on top. The satellite image in the background was taken by Sentinel-1 on the same day as the survey was performed.

Snow radar and laser scanner were operated throughout the campaign and experienced only intermittent, short, and minor issues. After no more AEM surveys were conducted, the flight altitude could be increased to 1500 ft ("Sea Ice High mission profile", Tables 1 & 3) that enabled extending the range of survey flights. Only subsets of snow radar data were processed into quicklook echograms in the field to confirm data quality (Fig. 9) as processing large amounts of data require a high-performance computing environment. Postprocessing the data and retrieving snow depth will take place after the campaign. Similarly, laser scanner data will be processed only after the campaign. Through sophisticated algorithms, range measurements from the laser scanner will be transformed to surface elevation and roughness data as well as snow freeboard over sea ice.

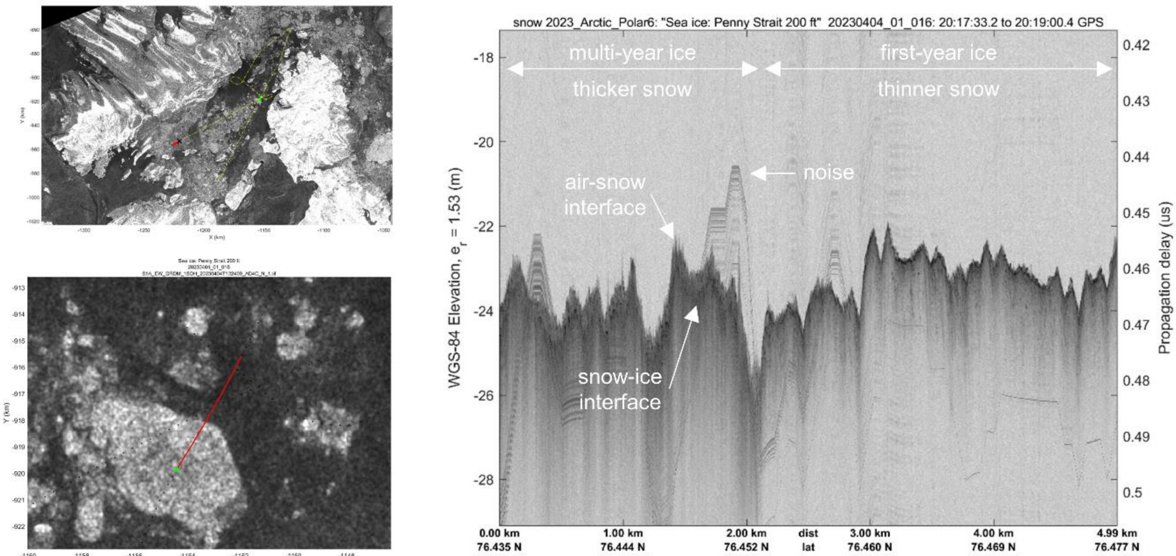

Fig. 9: (Top left) Overview of the acquired snow radar data along the yellow flight track and one example frame highlighted in green during the survey from Resolute Bay in Penny Strait on 4 April. **(Bottom left)** Close-up of the flight track where the example frame is now highlighted in red and the green dot marks the start of the frame. The background in the left panels is a Sentinel-1 SAR image from the survey day where older/rougher sea ice appears brighter and younger/smoother sea ice is darker. **(Right)** The 5-km example frame of quicklook-processed snow radar data where darker colours correspond to higher return power indicating interfaces between air, snow, and sea ice. The distance between the interfaces equals snow depth. The jaggedness of the surface is due to the quicklook processing using GPS data that is not yet post-processed.

Appendix: Survey Flight Descriptions

Below we provide for every day when survey flights were made

- specific flight information and problems encountered (if any)
- the flight track and auxiliary data

Air time/flight time, list of active sensors etc. is provided in Table 4.

Survey flight March 31, 2023

Specific flight information and problems encountered (if any)

Stable weather conditions, no clouds and low temperatures allowed a flight over the polynya northwards into the perennial ice zone and back. AEM-Bird surveys, together with laser scanner measurements were carried out on the way out. The flight began over open water behind the fast ice edge. Strong crosswinds over open water and in the new ice formation areas required frequent altitude corrections and interruptions of surveying activities at low altitude. Towards the north, the crosswinds decreased while the ice thickness increased steadily. The last 100 km of the survey were almost entirely dominated by MYI, with significantly higher pressure ridges (sails) and fewer leads. Flight altitude on the way back was 1500 ft as the laser scanner and snow radar were operated.

Flight setup/problems: Sea Ice Low (outbound) & High (inbound) Mission Profiles. On the way out, the laser scanner had several short failures and the snow radar had a initialization problem that was solved by the return leg of the flight. The MACS camera failed to initialize before take-off (no data for March 31).

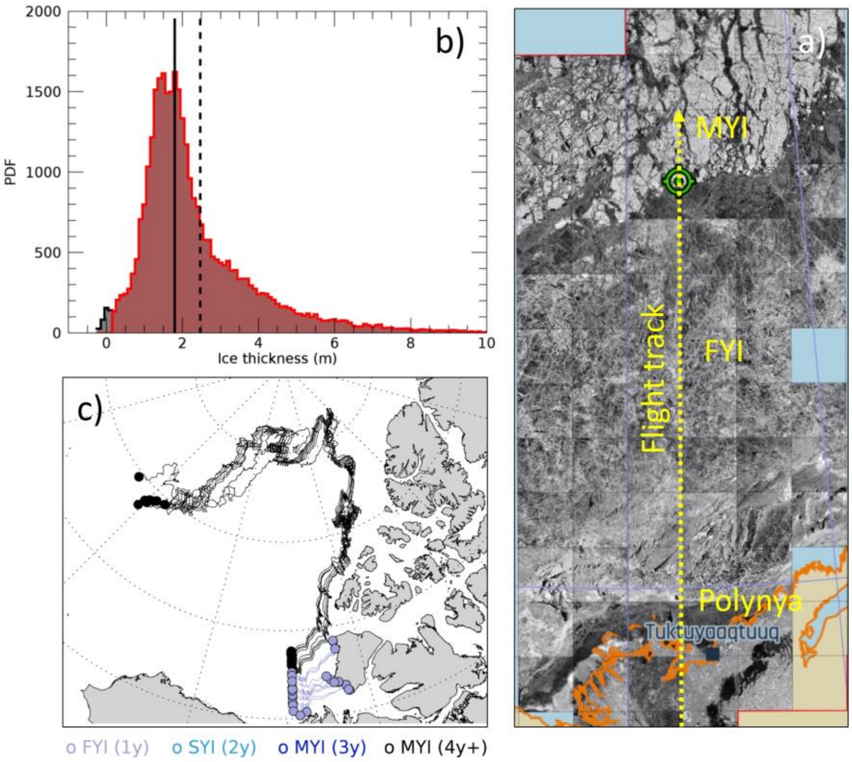

Fig. A1: a) Sea ice survey performed on Mar 31 from the fast ice edge, crossing the first-year (FYI) and multi-year (MYI) ice zone. The Senintel-1 radar image in the background was obtained on Mar 30. b) shows the AEM-Bird thickness histogram for the respective flight. Black solid and dashed line indicates the modal and mean thickness. c) Backtracking of surveyed sea ice using IceTrack. The tracks indicate pathways and source areas of surveyed FYI and MYI on Mar 31. FYI was primarily formed in near-by polynyas while MYI originated from the Beaufort Gyre.

Survey flight April 02, 2023

Specific flight information and problems encountered (if any)

On 2 April a mapping project was carried out over Trail Valey Creek (TVC) at 550 m a.s.l. using the laser scanner, snow radar and MACS camera (PI Julia Boike, Inge Grünberg, AWI). By comparing a DEM obtained during summer months with the April DEM, snow depths can be derived over a larger area. The spatial variability of observed snow depth will be investigated and linked to small scale terrain structure. The flight planning was done in the DLR/MACS flight planning software and transferred to the GARMIN cockpit systems. At the end of the mapping flight, two additional west-east and north-south transects were flown, along which high-resolution snow pits had been collected a few days before (contact Nick Rutter, nick.rutter@northumbria.ac.uk). In addition, drone-based terrain monitoring was conducted in the target area a few days prior to Polar 6 mapping (Branden Walker, bwalker@wlu.ca).

Flight setup/problems: The exposure time of the MACS camera had to be adjusted several times due to varying light conditions (clouds/sun). The thermal camera could not be successfully integrated at the beginning of the flight and was therefore switched off. Hence, flight was performed with RGB and NIR camera only. The laser scanner was operated without problems and with appropriate cross-track overlap. The snow radar also operated successfully throughout the flight.

Flight altitude:	1800 ft (550 m) a.s.l.
Laser scanner settings:	200 kHz, point spacing: ~0.7m , point density = ~ 2 pts/m³
MACS settings:	2.0 Hz Frequency, Cross Track Overlap 20 %, In Track 90%.
Snow radar settings:	Operated with the full 2-18 GHz bandwidth, footprint ~5-7 m
Weather conditions:	-20° C, partly cloudy (high ceiling)

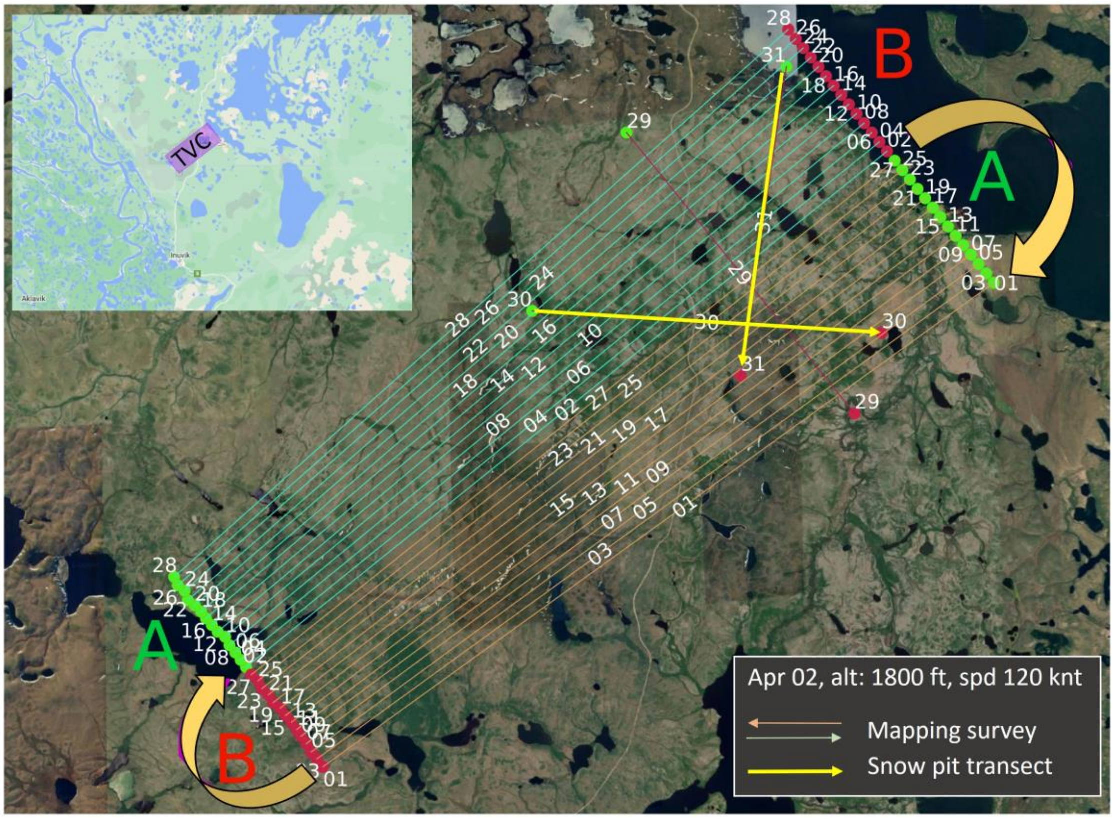

Fig. A2: Outline of Trail Valley Creek (TCV) mapping survey on April 2nd north of Inuvik. Flight was performed at 1800 ft above sea level.

Survey flight April 04, 2023

Specific flight information and problems encountered (if any)

Survey flight over Penny Strait covering different ice age classes on the way out and back in. The survey data will be used to investigate small-scale variability in ice thickness and snow and the interaction with the ocean and atmosphere.

Flight setup/problems: Sea Ice Low Mission Profile. MACS camera system failed to initialize

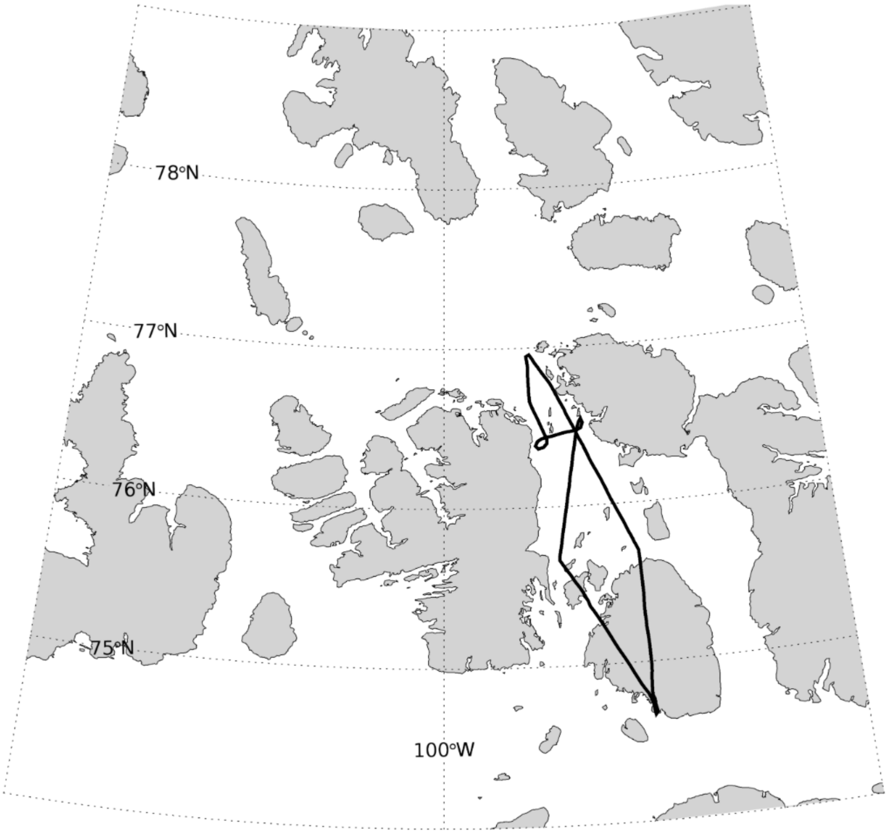

Fig. A3: Survey flight on 04 April, 2023

Survey flight April 05, 2023

Specific flight information and problems encountered (if any)

The AEM-Bird was damaged at the very beginning of the survey flight. Hence, survey activities were interrupted and Polar-6 returned to Resolute Bay.

Flight setup/problems: Sea Ice Low Mission Profile. MACS camera did not initialize. AEM-Bird damaged

Fig. A4: Survey flight on 05 April, 2023

Survey flight April 08, 2023

Specific flight information and problems encountered (if any)

On Saturday 8 April, we repeated a survey from the 2018 CASIMBO campaign (PI: Christian Haas) west of Axel Heiberg and Ellesmere Islands operating the snow radar and the laser scanner during a nearly 800 km long transect.

<u>Flight setup/problems</u>: Sea Ice High Mission Profile. No AEM-Bird. MACS camera not working.

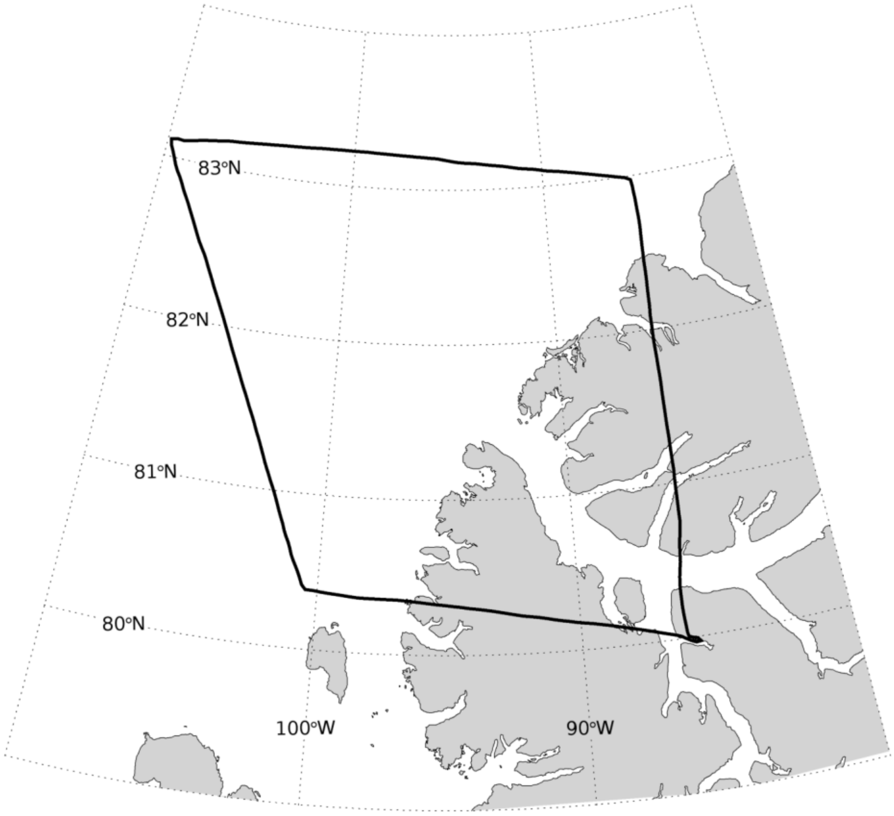

Fig. A5: Survey flight on 08 April, 2023

Survey flight April 19, 2023

Specific flight information and problems encountered (if any)

On Wednesday 19 April, we returned west to conduct a measurement flight along the Canadian airspace border just north of Alert. Data obtained extend the long time series of ice surface roughness surveys conducted in this area since the 2005s.

<u>Flight setup/problems</u>: Sea Ice High Mission Profile. No AEM-Bird. MACS camera not working.

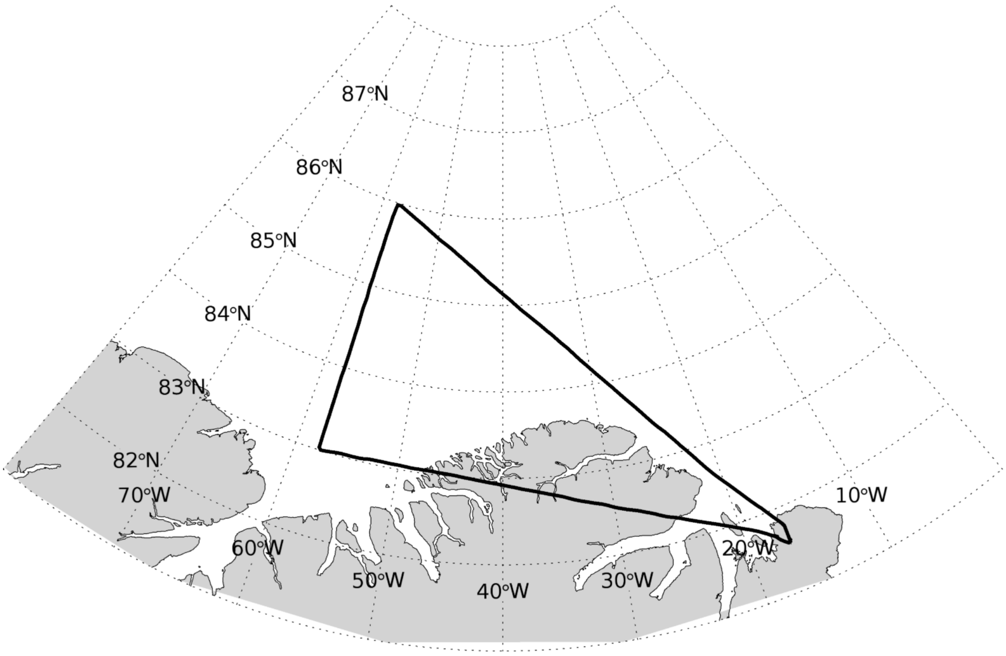

Fig. A6: Survey flight on 19 April, 2023

Survey flight April 20, 2023

Specific flight information and problems encountered (if any)

On the following day on Thursday 20 April, a survey flight was made towards the north up to 87 °N over Fram Strait area. Data obtained extend the long time series of ice surface roughness surveys conducted in this area since the 1993s. At the end of the flight, laser scanner calibration data were collected over the runway.

<u>Flight setup/problems</u>: Sea Ice High Mission Profile. No AEM-Bird. MACS camera not working.

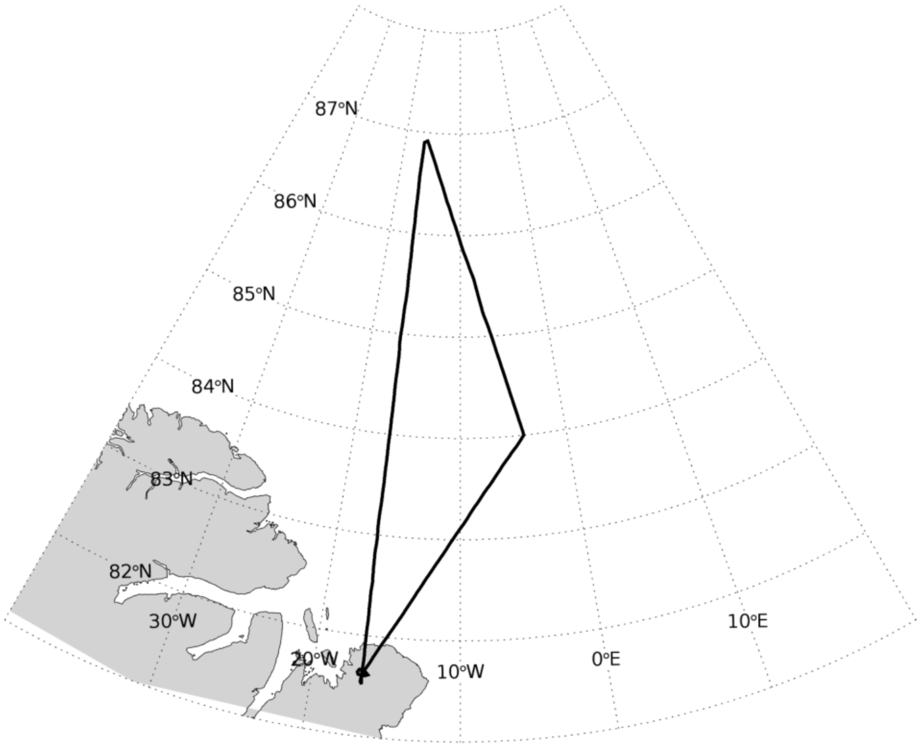

Fig. A7: Survey flight on 20 April, 2023

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