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ESA CryoVEx/KAREN and EU ICE-ARC 2017

Arctic field campaign with combined airborne Ku/Ka-band radar and laser altimeters, together with extensive in situ measurements over sea- and land ice

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DTU Space
National Space Institute
Technical University of Denmark

Technical Report
August 2019

METASENSING Radar solutions

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EUROPEAN SPACE AGENCY CONTRACT REPORT

ESA Contract No. 4000120131/17/NL/FF/mg (CCN1)

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Authors:
H. Skourup[1], A. V. Olesen[1], L. Sandberg Sørensen[1], S. Simonsen[1], S. M. Hvidegaard[1], N. Hansen[1], A. F. Olesen[1], A. Coccia[2], K. Macedo[2], V. Helm[3], R. S. Ladkin[4], R. Forsberg[1], A. E. Hogg[5], I. Otosaka[5], A. Shepherd[5], C. Haas[3,6] and J. Wilkinson[4]

[1] National Space Institute, DTU Space, Denmark
[2] MetaSensing BV, The Netherlands
[3] Alfred Wegener Institute for Polar and Marine Research, Germany
[4] British Antarctic Survey, Cambridge, UK
[5] University of Leeds, UK
[6] York University, Canada

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National Space Institute
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Front page: BAS Twin Otter (VP-FAZ) in CFS Alert. Credits: H. Skourup.

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ABSTRACT

The ESA CryoVEx/KAREN 2017 Arctic campaign is a very ambitious airborne and in situ campaign using combined Ka- and Ku-band airborne sensors (KAREN and ASIRAS) to validate CryoSat-2, Sentinel-3 and SARAL/AltiKa altimeter missions and to exploit the dual-frequency concept for future polar satellite missions. The concept builds upon the experience gained during ESA CryoVEx/KAREN 2016 fall campaign, which were the first ESA campaign to explore the dual-frequency airborne setup.

The collected data is unique and includes datasets along a total of five CryoSat-2, two Sentinel-3 and two dedicated SARAL/AltiKa ground tracks over sea ice in different locations representing different sea ice types and settings. The flights were coordinated with extensive large scale in situ work both over sea ice along a CryoSat-2 track from CFS Alert to 87N and along the EGIG line on the Greenland Ice Sheet from 47-38W covering different glacial zones. Crossings of the Greenland ice sheet includes multiple crossovers of all altimeter missions including CryoSat-2, Sentinel-3A and SARAL/AltiKa. For the first time four aircrafts with a variety of instruments were coordinated to measure along a CryoSat-2 ground track over the sea ice out of CFS Alert. This also included the first successful dedicated underflight of SARAL/AltiKa coordinated with Cambridge Bay in situ snow experiment (CamBay SnowExp), despite challenges due to the satellite being in a drifting orbit.

Names of authors:
H. Skourup, A. V. Olesen, L. Sandberg Sørensen, S. Simonsen, S. M. Hvidegaard, N. Hansen, A. F. Olesen, A. Coccia, K. Macedo, V. Helm, R. S. Ladkin, R. Forsberg, A. E. Hogg, I. Otosaka, A. Shepherd, C. Haas and J. Wilkinson

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Contents

1 Introduction

The 2017 airborne campaign was an ESA CryoSat-2 Validation Experiment (CryoVEx) primarily for CryoSat-2 validation, but also Sentinel-3 and SARAL/AltiKA, to monitor sea ice and land ice in the Arctic. The CryoVex/KAREN campaign also built upon the existing EU FP7 project ICE-ARC campaign. The airborne campaign was coordinated by National Space Institute, Technical University of Denmark (DTU Space), in cooperation with York University (YU) and Environment Canada (EC), and took place in spring 2017.

The campaign was divided in two separate campaigns referred to as phase 1 and phase 2. This was done first of all to ease the load on CFS Alert, but also to secure coordinated laser and radar flights with PanArcMIP EC/AWI Polar-5 and NASA Operation IceBridge.

Phase 1 took place March 20-31 and involved operations with ESA's Ku-band radar (ASIRAS), Dutch Company MetaSensing's Ka-band radar (KAREN) and laser scanner using chartered Twin Otter (reg. no.: TF-POF) from Norlandair, Iceland. The campaign covered sea ice flights in the Arctic Ocean and Baffin Bay, together with land ice flights over Devon icecap and the Greenland Ice Sheet. This part included a coordinated sea ice flight involving for the first time four aircrafts; ESA CryoVEx Twin Otter, PanArcMIP EC/AWI Polar-5, NASA Operation IceBridge and NASA wide-swath topographic mapper (GLISTN), carrying a suite of instruments to monitor the snow and sea ice along a CryoSat-2 ground track. In addition, flights were coordinated with large scale *in situ* work along the EGIG line of the Greenland Ice Sheet lead by University of Leeds.

Phase 2 took place April 5-23 and involved flights over sea ice and land ice from Cambridge Bay, CFS Alert, and Svalbard/Station Nord, as well as an intensive large scale sea ice *in situ* program with multiple landings between 82-86°N on sea ice along CryoSat-2 tracks north of CFS Alert. Two aircrafts were used during this phase. A Twin Otter from Kenn Borek Air, Calgary, was chartered for sea ice landings, and a British Antarctic Survey Twin Otter (VP-FAZ) was used to collect combined Ka-band radar (MetaSensing KAREN), laser and radiometer measurements, but also acting as safety back-up for the sea ice landings. This phase also included coordinated flights with Cambridge Bay Snow Experiment (CamBay SnowExp) and Austfonna ice cap in Svalbard.

This report is the final report of the experiments and summarizes the airborne and in situ field operations, instrument description and data processing together with first results. The report is an ESA CryoVEx contract report and part of EU ICE-ARC deliverable. Dedicated ICE-ARC flights are marked with green throughout the report.

<u>The primary objectives achieved during the campaign were:</u>

- To fly dual frequency (Ka/Ku-band) radar altimeters together with laser to study penetration depths in support of future satellite missions
- Coordinated sea ice underflights of CryoSat-2, Sentinel-3 and SARAL/AltiKa in different locations
- Coincident flights with PanArcMIP EC/AWI, NASA Operation IceBridge and GLISTN

- Large-scale in situ work on sea ice (Lincoln Sea and Cambridge Bay) and land ice (EGIG-line)

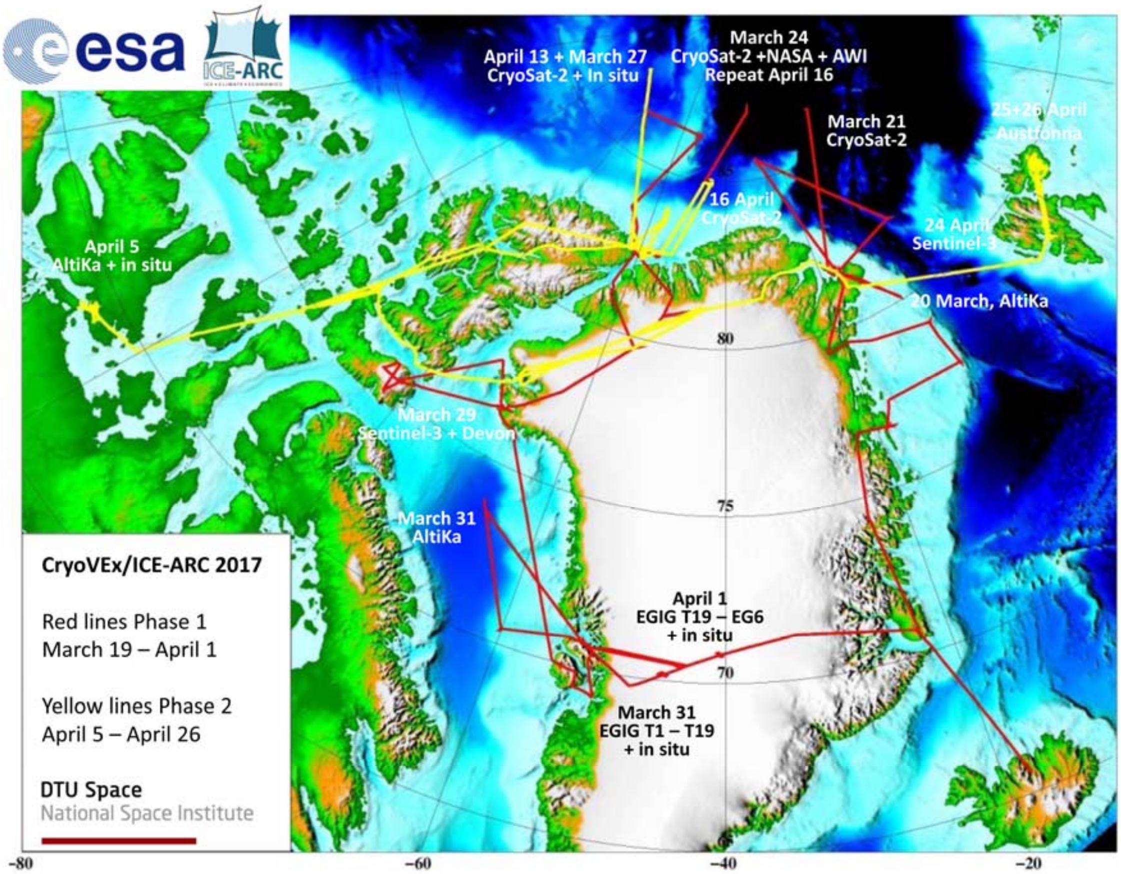

Figure 1: Overview of the flight tracks from the CryoVEx/ICE-ARC 2017 airborne campaign, phase 1 (red) and phase 2 (yellow). Satellite underflights and in situ sites have been marked.

2 Summary of operation

The CryoVEx/ICE-ARC 2017 airborne campaign was split into two operational periods. The first part, referred to as phase 1, basically circumnavigated Greenland north of 70°N, see red flight lines in Figure 1. The second part, referred to as phase 2, started out in Cambridge Bay, Nunavut, Canada and proceeded via CFS Alert to Svalbard, Norway, see yellow flight lines in Figure 1. A total of scientific flight hours were about 60 hours for each phase of the campaign.

Phase 1, took place March 19 – April 1, 2017 and included four underflights of CryoSat-2, one Sentinel-3 and two AltiKa over sea ice (Section 6.1), and was coordinated with large scale in situ work on the old traverse, the EGIG line, on the Greenland Ice Sheet (Section 6.2.1). The Norlandair Twin Otter (reg: TF-POF), which is the same aircraft as used throughout previous CryoVEx campaigns, was chartered for phase 1. The instrument installation and test flights took place in Akureyri, Iceland, March 15-18, following the general instrument certification for the aircraft obtained in 2006 (Hvidegaard and Stenseng, 2006). The exceptional setup was that for the first time four aircrafts were jointly underflying a Cryosat-2 ground track, carrying a variety of instruments to compliment the dual-frequency setup. This was done in the Lincoln Sea on March 24, and included Norlandair Twin Otter with Ka-band radar (KAREN), Ku-band (ASIRAS) and Airborne Laser Scanner (ALS), AWI Polar-5 towing an electromagnetic sensor to measure the sea ice thickness, Operation IceBridge P3 with ATM and snow radar, and NASA wide-swath topographic mapper (GLISTN). A more detailed description of the science flights can be found in Chapter 6. The flight program was very tight, leaving no space for delays. Luckily, the weather was favorable and all planned flights were achieved within the estimated time.

The primary aim of phase 2 was to support the in situ work out of CFS Alert, both by taking coincident measurements, but also to act as safety backup for the in situ team aircraft (Ken Borek Twin Otter) which was used for multiple landings on the drifting sea ice to transport the in situ group to the different sites (see Section 6.1.2). Phase 2 was supported by the British Antarctic Survey Twin Otter (VP-FAZ), which was used for similar measurements in spring 2015 (Hvidegaard et al., 2017). The instrument installation took place March 27-April 3 in Springbanks airport, Calgary, Canada. April 4-5 the aircraft was transferred to Cambridge Bay, Nunavut, Canada, where a large *in situ* program "CamBay SnowExp" to measure the snow and ice properties along a SARAL/AltiKa ground track was setup with UK, US and Canadian scientists (Section 6.1.4). During phase 2 a total of four CryoSat-2, one SARAL/AltiKa and one Sentinel-3 underflight over sea ice was measured. In addition a pattern of parallel lines, with a similar angle as ascending CryoSat-2 tracks were also flown over Austfonna similar to CryoVEx 2016 spring campaign (Skourup et al., 2016). In addition about 5 flight hours were dedicated to make a tight grid over land in Cambridge Bay area to validate a high-resolution DEM from NASA (Section 6.3). In general the weather was favorable. However, some delays were introduced due to waiting for weather and de-mounting of wheel-skies, which only could be performed in Resolute Bay. The second phase of the campaign was followed by an airborne ESA campaign to test a novel "cold atom" gravimeter in an aircraft in Iceland in cooperation with ONERA, France (campaign described in a separate report).

The flight altitude during survey is typically 300 m agl, limited by the range of the laser scanner, and the nominal ground speed is 135 knots. The aircraft is equipped with an extra ferry tank permitting longer flights (5-6 hrs), and an autopilot for better navigation accuracy. In good conditions the across-track accuracy is down to a few meters using a custom-made navigation system connected to geodetic GPS receivers. Calibration flights of the instruments over buildings and runways were performed whenever possible. For a more detailed description see Section 5.3 and 5.4.

The airborne science team during phase 1 consisted of Arne V. Olesen, Louise Sandberg Sørensen from DTU Space, Alex Coccia from MetaSensing, and ESA technical officer Malcolm Davidson. In phase 2 the science team consisted of Henriette Skourup (Cambridge Bay to Svalbard) and Sebastian B. Simonsen (Svalbard) from DTU Space. Arne V. Olesen (DTU Space), Alex Coccia (MetaSensing) and Russell Ladkin (British Antarctic Survey) assisted with the instrument installation in Calgary in the aircraft prior to the campaign.

The sea ice in situ team working out of CFS Alert (April 11-18) was lead by Christian Haas (Alfred Wegener Institute/York University) and supported by Ken Borek Twin Otter equipped with skies. The team consisted of Christian Haas, Justin Beckers (University of Alberta), Josh King and Arvids Silis (both from Environment Canada), Julienne Stroeve (University College London), and Jeremy Wilkinson (British Antarctic Survey).

Based on experience from CryoVEx/KAREN 2016 campaign, the in situ team working on the EGIG line used a ski-equipped Twin Otter from Norlandair, which is more flexible with respect to weather and range, when compared to helicopter as used in 2016. The team consisted of Sebastian Simonsen (DTU Space), Anna Hogs (University of Leeds), Andy Shepard (University of Leeds) and Alessandro Di Bella (DTU Space).

Cambridge Bay SnowExp 2017 (Section 6.1.4) was lead by Jeremy Wilkinson (British Antarctic Survey). The experiment was based out of the recently established research facility Canadian High Arctic Research Station (CHARS), in Cambridge Bay, Nunavut, Canada. Beside Jeremy Wilkinson the ground team consisted of: Woosok Moon (British Antarctic Survey), Andrew Barrett (NSIDC), Francois Guerraz (Orographic Lift Ltd), Dwayne Beattie (POLAR), Donald McLennan (POLAR), Daniel Kramer (POLAR), Angulalik Pedersen (POLAR), Julienne Stroeve (University College London), Isobel Lawrence (University College London), Vishnu Nandan (University of Calgary) and Randy Scharien (University of Victoria).

An overview of the flights is found in Table 1 and 2 along with a detailed "day-to-day"-report in Section 2.1. Operator logs and detailed plots of flight tracks are provided in Appendix 9.2.

Table 1: Overview of CryoVEx/KAREN 2017 flights, phase 1. Initials of survey operators are Arne V. Olesen (AVO), Louise Sandberg Sørensen (SLSS) and Alex Coccia (AC).

Date	DOY	Flight	Track	Take off UTC	Landing UTC	Airborne	Airborne accumulated [dd:hh:mm]	Survey operator
18-03-2017	77		Test Flight AEY ?			00:00	00:00:00	AVO/SLSS/AC
19-03-2017	78	A	AEY-CNP	09:07	11:38	02:31	00:02:31	AVO/SLSS/AC
19-03-2017	78	B	CNP-DMH	12:04	15:34	03:30	00:06:01	AVO/SLSS/AC
20-03 2017	79	A	DMH-ULS-TobiasØ-STN	10:55	16:03	05:08	00:07:39	AVO/SLSS/AC
20-03 2017	79	B	STN-ALTIKA-STN	16:06	18:36	02:30	00:10:09	AVO/SLSS/AC
21-03 2017	80	A	STN-CS2-STN	10:25	15:21	04:56	00:15:05	AVO/SLSS/AC
21-03 2017	80	B	STN-TRIANGLE-STN	16:01	21:08	05:07	00:20:12	AVO/SLSS/AC
22-03 2017	81		NRD-GrIS-YLT	14:23	18:12	03:49	01:00:01	AVO/SLSS/AC
24-03 2017	83		YLT-CS2-YLT	14:22	20:12	05:50	01:05:51	AVO/SLSS/AC
27-03 2017	86		YLT-CS2-inSitu-YLT	13:54	18:18	04:24	01:10:15	AVO/SLSS/AC
28-03 2017	87		YLT-Peterman-GrIS-TAB	13:56	17:53	03:57	01:14:12	AVO/SLSS/AC
29-03 2017	88		TAB-S3A-DEVON-TAB	13:22	18:38	05:16	01:19:28	AVO/SLSS/AC

30-03 2017	89	A	TAB-BaffinBay-DISKO-JAV	11:49	16:18	04:29	01:23:57	AVO/SLSS/AC
30-03 2017	89	B	JAV-JQA	16:45	17:29	00:44	02:00:41	No Survey
31-03 2017	90	A	JQA-ALTIKA-JQA	08:00	12:08	04:08	02:04:49	AVO/SLSS/AC
31-03 2017	90	B	JQA-EGIG-JQA	13:52	17:20	03:28	02:08:17	AVO/SLSS/AC
01-04 2017	91	A	JQA-EGIG-CNP	09:25	13:47	04:22	02:12:39	AVO/SLSS/AC
01-04 2017	91	B	CNP-AEY	14:11	16:21	02:10	02:14:49	No Survey
Total							**60h 18m**	

Table 2: Overview of CryoVEx/KAREN 2017 flights, phase 2. Initials of survey operators are Henriette Skourup (HSK), Sebastian B. Simonsen (SSIM), Alex Coccia (AC) and Russell Ladkin (RL).

Date	DOY	Flight	Track	Take off UTC	Landing UTC	Airborne	Airborne accumulated [dd:hh:mm]	Survey operator
05-04-2017	95	b	YCB-AltiKa-YCB	21:25	23:45	02:20	00:02:20	RL/AC
07-04-2017	97	a	YCB-TER-YCB	19:18	19:51	00:33	00:02:53	HSK/RL
07-04-2017	97	b	YCB-TER-SI-YCB	23:32	02:04	02:32	00:05:25	HSK/RL
08-04-2017	98		YCB-TER-YCB	23:31	01:45	02:14	00:07:39	HSK
11-04-2017	101		YCB-McClintock-YRB	15:40	19:40	04:00	00:11:39	HSK
12-04-2017	102	a	YRB-YEU	13:58	17:01	03:03	00:14:42	HSK
12-04-2017	102	b	YEU-YLT	18:03	20:08	02:05	00:16:47	HSK
13-04-2017	103		YLT-inSitu-YLT	13:58	19:36	05:38	00:22:25	HSK
16-04-2017	106		YLT-CS37255MOW-YLT	13:10	18:19	05:09	01:03:34	HSK
18-04-2017	108		YLT-ShearZone-IceBridge-YLT	13:37	17:14	03:37	01:07:11	HSK
19-04-2017	109	a	YLT-YEU	12:57	15:20	02:23	01:09:34	No Survey
19-04-2017	109	b	YEU-YRB	15:58	18:32	02:34	01:12:08	No Survey
20-04-2017	110	a	YRB-YGZ	13:37	15:40	02:03	01:14:11	HSK
20-04-2017	110	b	YGZ-NAQ	16:31	18:13	01:42	01:15:53	HSK
21-04-2017	111		NAQ-A3-XX-NAQ	11:56	16:54	04:58	01:20:51	HSK
24-04-2017	114	a	NAQ-H-STN	11:21	15:32	04:11	02:01:02	HSK
24-04-2017	114	b	STN-S3-LYR	16:22	19:21	02:59	02:04:01	HSK
25-04-2017	115		LYR-Austfonna-LYR	09:43	12:14	02:31	02:06:32	SSIM/HSK
26-04-2017	116		LYR-Austfonna-LYR	07:55	12:39	04:44	02:11:16	SSIM
Total							**60h 23min**	

2.1 Day to day

The airborne part of CryoVEx/KAREN 2017 campaign progressed as follows:

2.1.1 Phase 1

March 14	Scientists Copenhagen - Reykjavik
March 15	Scientists Reykjavik – Akureyri. Start installation in POF
March 16-18	Instrument installation in POF, and test flight near Akureyri
March 19	Transit flight to Constable Point. Survey flight Constable Point – Danmarkshavn.
March 20	Survey flight Danmarkshavn – Station Nord.
March 21	Two survey flights out of Station Nord. One sea ice flight. One CS2 underflight.
March 22	Ice sheet survey flight Station Nord – Alert.
March 23	No flights due to poor weather
March 24	Survey flight out of Alert. CS2 underflight coordinated with AWI and NASA.
March 25-26	No flights (weekend)
March 27	Survey flight out of Alert. CS2 underflight
March 28	Survey flight Alert – Thule Air Base
March 29	Survey flight over Devon ice cap, combined with AltiKa track.
March 30	Survey flights Thule Air Base – Ilulissat - Qaarsut
March 31	Two survey flights out of Qaarsut: one Altika track and one coordinated with KAREN ground team on the EGIG line.
April 01	Survey flight Qaarsut – Constable Point. Coordinated with KAREN ground team on EGIG line. Transit flight Constable Point – Akureyri. Un-mount instruments.
April 02	Scientists Akureyri – Copenhagen/Canada

2.1.2 Phase 2

March 27 - April 3	Installation Springbanks airport, Calgary, Canada
April 4	Flight Calgary to Yellowknife
April 5	Flight Yellowknife to Cambridge Bay, followed by underflight of AltiKa track coincident with snow measurements on the ground over both land and sea ice. Reflectors placed perpendicular to flight lines. GPS not logging.
April 6	HSK arrive Cambridge Bay, Poor visibility, no flights
April 7	Poor visibility, tried a noon flight, but too low clouds, no ALS signal from the ground. Late flight to cover terrestrial flight + sea ice flight, the planned corner reflectors were not in place
April 8	late flight to cover the last parts of terrestrial flight + 1 runway overflight
April 9-10	Weather days. Blizard. Drifting snow and high winds gusting 60 km/h
April 11	Excellent weather YCB. Flight YCB via waypoints in McClintock channel to Resolute
April 12	Resolute to Eureka, survey on the way, old CS2-track. Eureka to CFS Alert, problems with scanner software. The scanner did not synchronize automatically, but managed to circumvent by using RiTerm.

April 13	In situ line to 87.5N both ways. Problems with Camera PC, could see nothing on the screen. Used HSK personal laptop. In situ team at site 5
April 14	No flying due to Easter. Alert closed
April 15	No flying due to poor visibility and light snow in Alert
April 16	CryoSat-2 track 37225 to the NE. Survey area 50kmx1.5km consisting of 5 parallel tracks 350m apart on the drifting ice at about N84.5°-85.0° W40°-45°. Perfect timing of CS2 and airborne measurements in the survey area. En route follow CS2 NE track also flown in phase 1 on March 24th, together with Icebridge formed in NE Nares Strait. Nice area with open leads. In situ work sites 1 and 4
April 17	Day off, no flying with BAS. In situ work at NE-line
April 18	Flight to shear zone MOW, and icebridge. Windy N/NW
April 19	Alert transit to Resolute Bay via Eureka. No surveying
April 20	Resolute Bay to Qaanaaq via Grise Fjord. Measuring in Jones Strait. Parts too cloudy including Hells Gate. Snowing in Qaanaaq
April 21	Returned half-way to Station Nord due to bad weather at Station Nord. Excellent weather in Qaanaaq. No weather improvements expected at Station Nord within the next 24 hrs
April 22-23	No flying due to bad weather at STN
April 24	SSIM arrive Longyearbyen the night between 23rd and 24th. Flight Qaanaaq to station Nord, measuring the remaining part of the ice sheet and Independence Fjord. Excellent weather at Station Nord. Continue Station Nord to Longyearbyen following Sentinel-3 track 20170424T180900
April 25	Flight to Austfonna, the survey only manage to measure on the west-ridge towards Etonbreen, before the survey had to be aborted due to clouds-
April 26	Flight to Austfonna. Cloudy condition, but survey of most of the CryoSat track in basin 3. HSK returned to CPH
April 27	Weather in LYR made surveying impossible. The crew on VP-FAZ went to Tromsø, to start the return to Cambridge, UK
April 28	SSIM return to CPH

3 Hardware installation

3.1 Phase 1

The hardware installation in the Norlandair Twin Otter (TF-POF) consisted of the following instruments:

- MetaSensing Ka-band radar altimeter KAREN
- ESA Ku-band interferometric radar ASIRAS
- DTU Space Airborne Laser Scanner (ALS) of the type Riegl LMS Q-240i-60
- Four geodetic dual-frequency GPS receivers of type Javad Delta (AIR1-4), where AIR4 was used to support ASIRAS time tagging
- An Inertial navigation system (INS) of the type Honeywell H-764G
- An Inertial navigation system (INS) of the type iMAR RQH (backup)
- A NovaTel integrated GPS-INS system of type SPAN-CPT to support KAREN (backup)
- Slant looking DSLR camera (Canon 60D)

The KAREN sensor was for the first time successfully tested during CryoVEx/KAREN 2016 fall campaign (Skourup et al., 2017a). Since then, the horn antennas have been replaced with new Microstrip patch array antennas, see Figure 2, which reduces the across-track resolution from 20 m to 12 m (see Section 5.5).

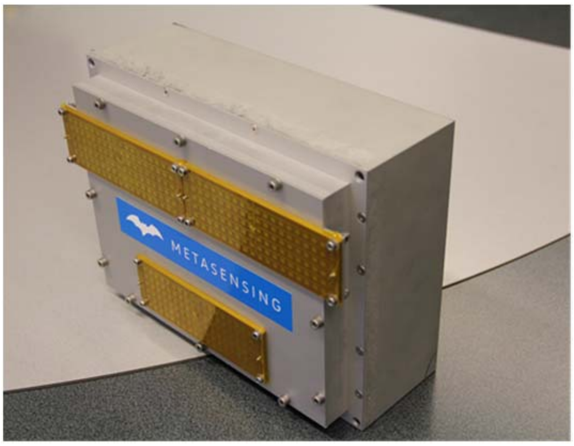

Figure 2: KAREN Radio Frequency (RF) enclosure with updated microstrip patch antennas.

To accommodate the updated KAREN sensor, it was not necessary to raise the mounting plate, as was the case during CryoVEx/KAREN 2016 fall campaign. This results in a more stable instrument setup. The horizontal position of the mounting plate, and thus the ALS, was similar to CryoVEx/KAREN 2016 fall campaign (Skourup et al., 2017). To avoid shadow effects from the hull of the aircraft the ALS was tilted slightly backwards. The KAREN control unit was fitted into the rear ASIRAS rack, see Figure 3 and 5.

The installation of the ASIRAS system was identical to the setup used throughout the previous CryoVEx campaigns (e.g. Skourup et al., 2013). A Javad Delta receiver AIR4 was used to support ASIRAS time-tagging. The bottom view of the aircraft is shown in Figure 4, with the external ASIRAS antenna, and the KAREN sensor in the hatch.

The four geodetic dual-frequency GPS receivers (AIR1, AIR2, AIR3 and AIR4), operated to log precise aircraft positioning, were connected to two separate GPS antennas ("front" and "rear") through antenna beam splitters. The GPS antennas are permanently installed on TF-POF. Information about the antenna constellation is provided below:
Front antenna:

- AIR1
- AIR2
- AIR3 from 23-03-2017

Rear antenna:

- AIR3 until 22-03-2017
- AIR4

The logging rates of the AIR2 and AIR3 were 1 Hz, whereas AIR1 and AIR4 was logging at 2 Hz. The higher logging rate for AIR1 was chosen to obtain a higher precision for the on-board navigation system. AIR4 was also used to support ASIRAS time tagging. Offsets between GPS antennas and KAREN, ASIRAS and ALS reference points are given in Table 3.

To record the attitude (pitch, roll and heading) of the aircraft, three inertial navigation systems (INS) were used. The primary unit is a medium grade INS of type Honeywell H-764G mounted in the baggage compartment on the mounting plate together with the ALS (Figure 6). This unit collects data both in a free-inertial and a GPS-aided mode at 50 Hz. Specified accuracy levels in roll and pitch are better than 0.1˚, and usual accuracy is higher than this. A super-precise INS strap-down unit of type iMAR RQH, which has the potential to measure the gravity field (Jensen et al., 2017), was installed in the cabin next to the front operator seat, see Figure 3 and 5. Finally, a light-weight (2.28 kg) integrated GPS-INS of type NovaTel SPAN-CPT with a nominal accuracy similar to the H-764G, was installed in the rear rack together with the KAREN control unit. The Honeywell INS was connected to the front antenna until 22-03-2017, after which it was changed to the rear antenna. The iMAR was connected to the rear GPS antenna during the entire phase 1.

The setup of the instruments in the aircraft is shown in Figure 3 and pictures of the various instruments are shown in Figure 4-7.

Table 3: The dx, dy and dz offsets for the lever arm from the GPS antennas to the origin of the laser scanner, the back centre of the ASIRAS antenna (see arrow Figure 3), and the KAREN reference point.

To laser scanner	dx (m)	dy (m)	dz (m)
from front GPS antenna	- 3.60	+ 0.49	+ 1.58
from rear GPS antenna	+ 0.10	- 0.38	+ 1.42
to ASIRAS antenna	**dx (m)**	**dy (m)**	**dz (m)**
from front GPS antenna	-3.37	+0.47	+2.005
from rear GPS antenna	+0.33	-0.40	+1.845
to KAREN reference point	**dx (m)**	**dy (m)**	**dz (m)**
from front GPS antenna	-3.71	+0.47	+1.82
from rear GPS antenna	-0.01	-0.40	+1.66

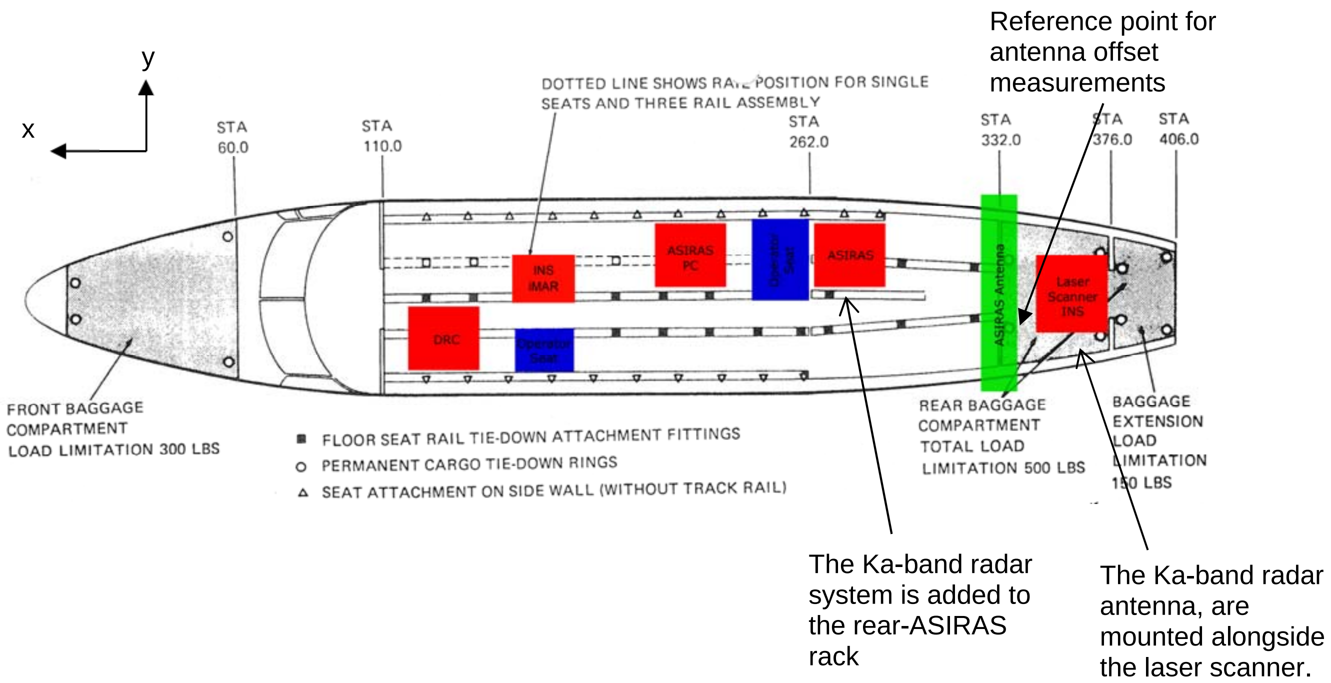

Figure 3: Overview of instrument setup in the TF-POF Twin Otter aircraft

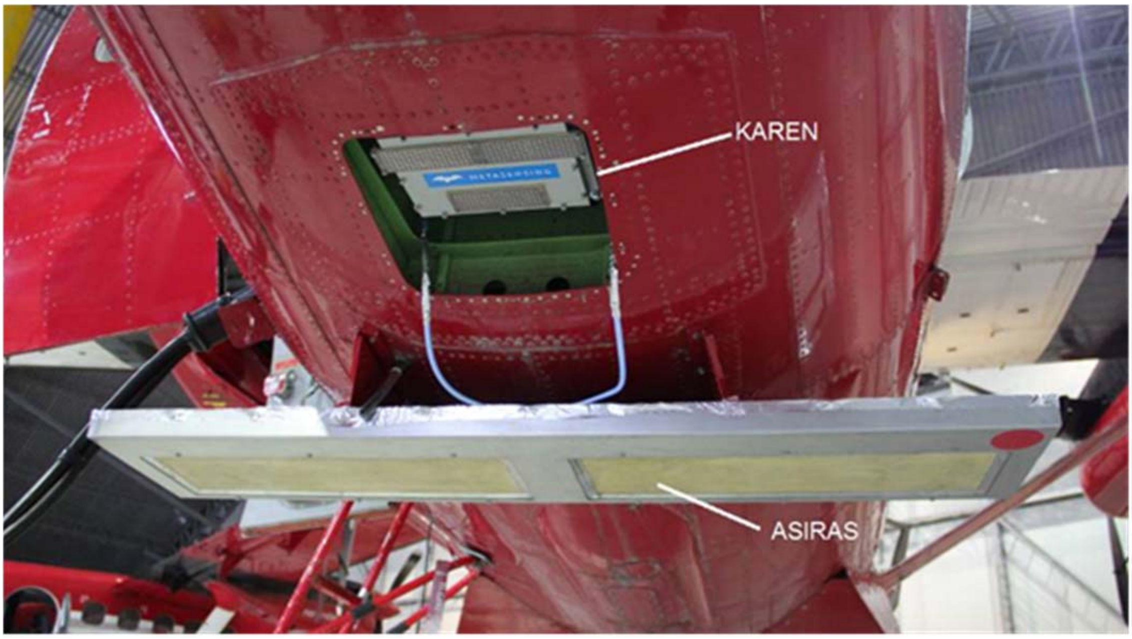

Figure 4: Bottom view of the Norlandair Twin-Otter TF-POF showing KAREN and ASIRAS antennas.

Figure 5: View of cabin in aircraft; Left picture: Rack with Ka-band altimeter (front right), rack for ALS, GPS and INS (rear left). Right picture: iMAR strap-down INS, grey box attached to the floor (lower right).

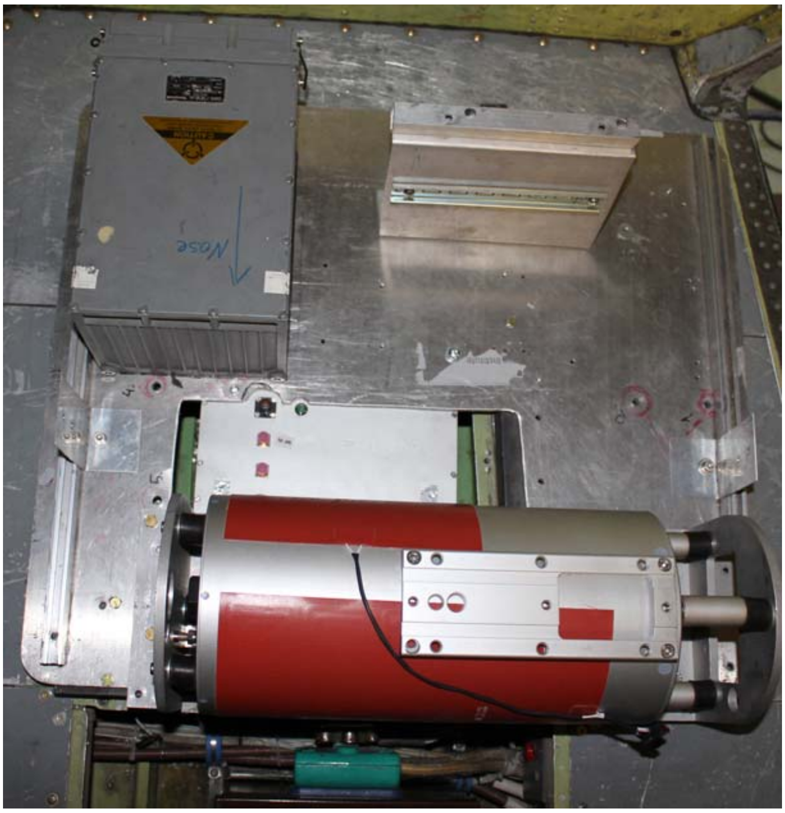

Figure 6: The mount-plate seen from above. The ALS is seen in the lower part of the image just below the Ka-band RF module. The EGI is seen in the upper left corner.

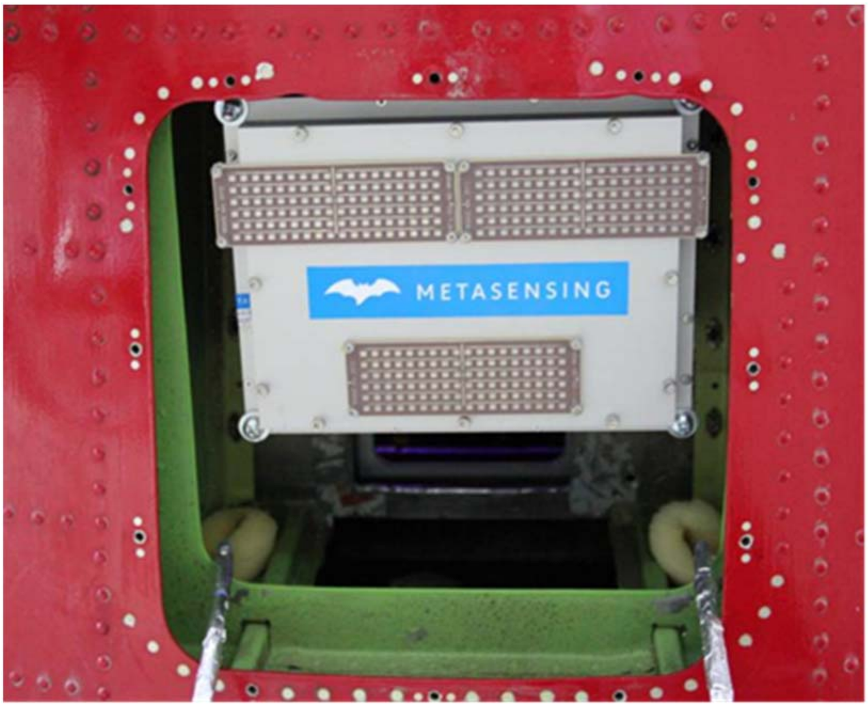

Figure 7: Detail of the KAREN sensor: the new patch antennas allow for a compact installation. Part of the ALS is seen below the KAREN sensor as a bluish window.

3.2 Phase 2

The hardware installation in the BAS Twin Otter (VP-FAZ) consisted of the following instruments:

- MetaSensing Ka-band radar altimeter KAREN
- BAS Airborne Laser Scanner (ALS) of the type Riegl LMS Q-240i-80
- 1-2 geodetic dual-frequency GPS receivers of type Javad delta (AIR1-2)
- An Inertial navigation system (INS) of the type Honeywell H-764G
- An Inertial navigation system (INS) of the type OxTS xNav 550 (backup)
- A NovaTel integrated GPS-INS system of type SPAN-CPT to support KAREN (backup)
- BAS Radiometer. Eppley PIR and PSP sensors fitted to the roof and underside of the aircraft
- BAS infra-red thermometer. Heimann model KT19.82 mounted in the floor hatch panel
- BAS Nadir looking DSLR Camera (Canon EOS 7D)

The ALS setup is similar to the setup in the same aircraft during EU ICE-ARC/ESA FinExp campaign in 2015 (Hvidegaard et al., 2017). All instruments were mounted in the camera hatch located below the floor in the cabin (Figure 8-10), except for the Honeywell INS, which were mounted on the floor below the operator seat in the cabin (Figure 8).

Camera Hatch Antenna (F):

- AIR1 Javad Delta
- AIR3 Javad Delta, mounted before flight 13-04-2017

The instruments were mounted in the aircraft and tested in Calgary before the departure for the phase 2 campaign. The lever arms from GPS antenna to KAREN and ALS reference points are given in Table 4, and the hardware installation can be seen in Figure 8-11.

Table 4: The dx, dy and dz offsets for the lever arm from the GPS antenna to the origin of the laser scanner and the KAREN reference point.

To laser scanner	dx (m)	dy (m)	dz (m)
from Camera Bay GPS antenna (F)	+ 0.27	+ 0.05	+ 1.55
To KAREN reference point	**dx (m)**	**dy (m)**	**dz (m)**
From Camera Bay GPS antenna (F)	+0.16	+0.12	+1.68

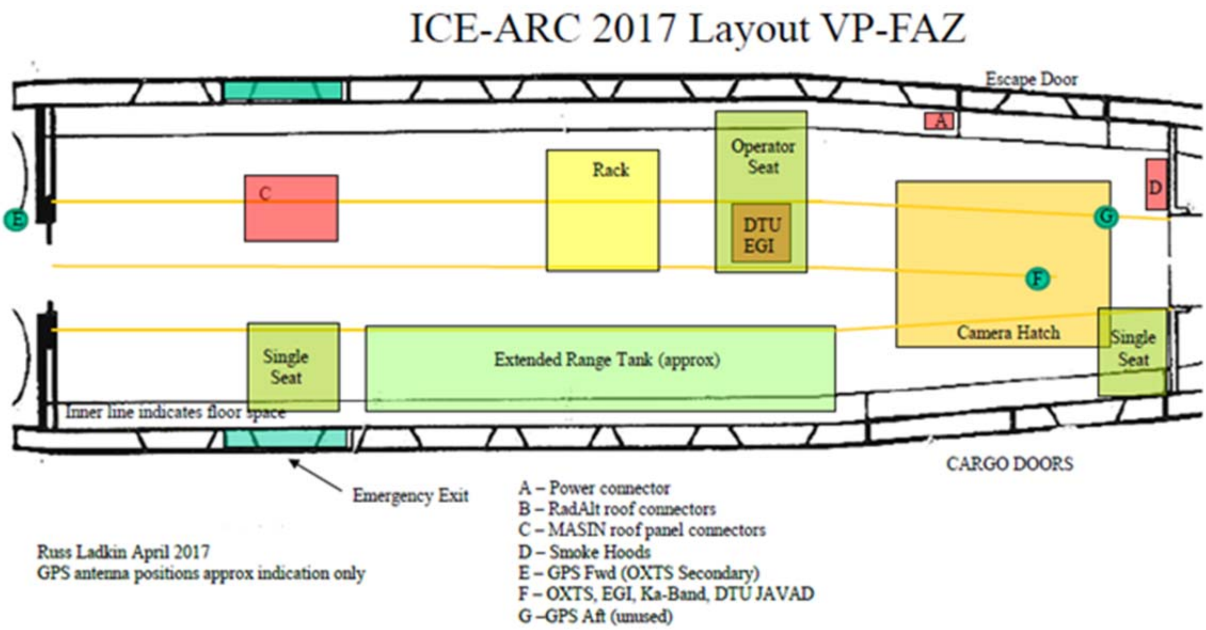

Figure 8: Overview of instrument setup in the VP-FAZ Twin Otter aircraft

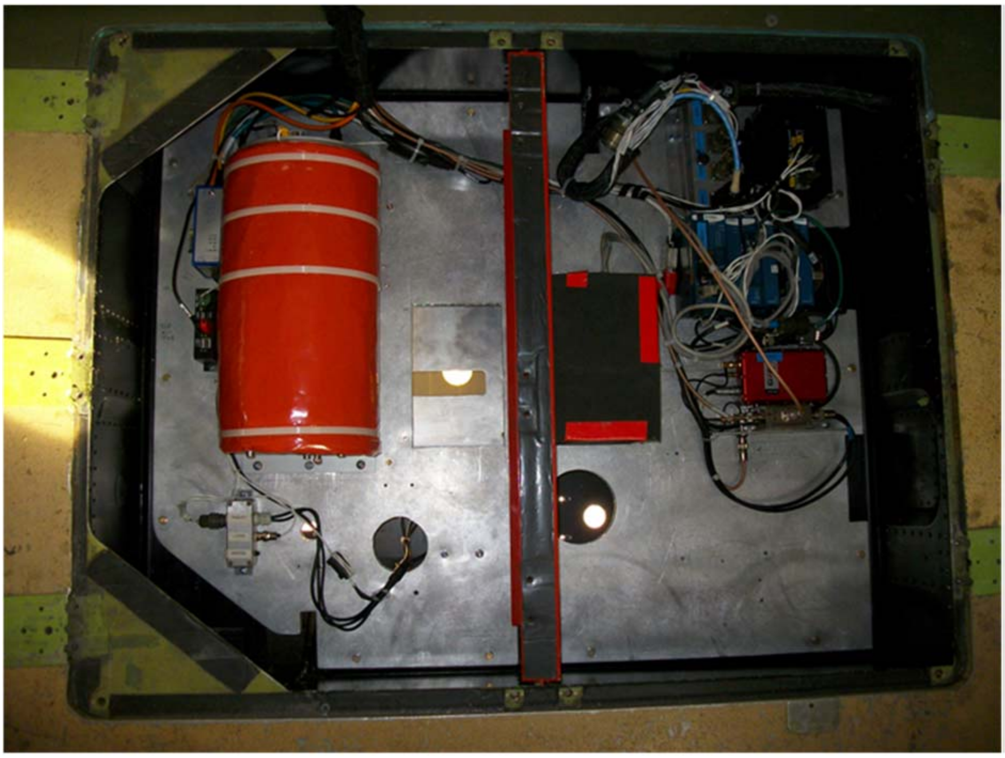

Figure 9: Instrument installation in the camera bay below the floor in the Twin Otter cabin; ALS (left), OxTS INS (middle right) and Trimble GPS receiver (lower right). Note ALS and OxTS INS axis are mounted along aircraft centre line. Installation: Forward to left. Aircraft right is at the top.

Figure 10: Bottom view of the BAS Twin-Otter VP-FAZ showing KAREN, ALS together with radiometers and camera.

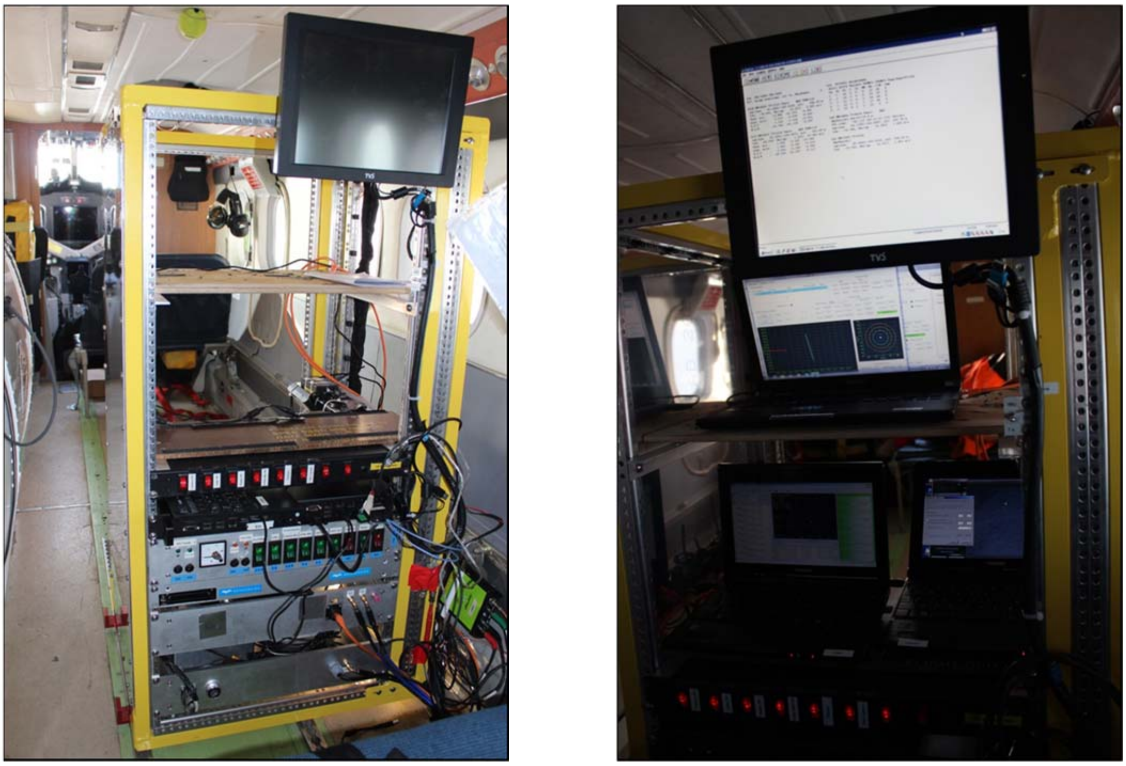

Figure 11: Rack setup in BAS Twin Otter VP-FAZ. All instruments are fitted in one rack see image on the left from below; KAREN altimeter, power unit, rack PC to support Honeywell INS, and another power unit. Control PC's are shown in right image from below; ALS (left), camera (right), KAREN, Honeywell INS.

4 Overview of acquired data

Data from the various instruments were acquired where feasible, considering the limited range of the ALS system and the weather. An overview of all acquired data is listed in Table 5 and 6.

The sampling frequency of the KAREN sensor was set to 25 MHz corresponding to one sampling each ~30cm on the ground. The high sampling frequency results in a large amount of 360 GB of raw data per hour, plus a few MB of navigation data (dedicated GPS/IMU module). Acquisitions have been manually started and stopped by the operator according to the area which was flown; data sets of typically ~10 minutes or ~20 minutes duration have been logged. At the end of the campaign the raw data amount is ~11.4 TB (7 TB phase 1 and 4.4 TB phase 2). Due to the large amount of data, and limited backup possibilities during phase 2, some less prioritized flights have not been logged. During the flight and at the end of each acquisition day a quick data look was performed on randomly selected dataset to assess the quality and eventually adjusting the Pulse Repetition Frequency (PRF) according to the flight altitude.

Due to mal-function of PC2, all ASIRAS data were acquired in Low Altitude Mode (LAM) with low along-track resolution (LAMa). This allows flight at an altitude of 300 m, which is within the operational range of the ALS system and a relative low data volume of about 28 GB per hour. A total of 1.19 TB raw ASIRAS data were collected during phase 1 of the CryoVEx/ICE-ARC 2017 campaign. The data were stored on hard discs as ASIRAS level 0 raw data in the modified compressed format (Cullen, 2010).

In general, the ALS worked well. A total inspection of the instrument was performed at Riegl prior to the campaign, including dry out, re-flush of nitrogen, and re-ceiling to try to minimize the problems with moisture on the instrument window, which have been a problem in recent CryoVEx campaigns in cold conditions (-25°C and below). This seems to have improved the instruments capabilities, and no loss of data was observed during phase 1 due to moisture on the instrument window. During all flights in phase 1 the last pulse option was used, to avoid internal reflections of the aircraft fuselage due to the limited space. During phase 2, the more protected setup of the instrument in the camera bay never caused any problems with moisture at cold temperatures. The data volume obtained by the ALS is about 250-300 MB per hour, which is a relative small amount, when compared to the ASIRAS data volume. During the campaign a total of 32.8 GB (18.3 GB phase 1 and 14.5 GB phase 2) ALS data was acquired.

The airborne GPS units logged data internally in the receivers during flight, which were downloaded upon landing on laptop PCs. The GPS reference stations listed in Tables 5 and 6 are described in further detail in Section 5.1. During phase 1 some problems occurred with the Honeywell INS during the first part of the campaign (until 23-03-2017), which was solved by changing the antenna constellation, see Section 3.1. However, coincident data were obtained with the iMAR system leaving no gaps in the data set. The Honeywell performed well during phase 2, except the flight on April 18 (DOY 108), where the PC froze, and new files had to be started twice during the survey, leaving few minutes gaps in the data set.

Due to limited space in the instrument bay, during phase 1, it was not an option to add a camera. As an alternative a camera was mounted on a rear window in the cabin using a Fat Gecko camera mount, to take slant looking images out of the window. These images were only acquired for sea ice flights. In phase 2 a high-resolution nadir-looking DSLR camera was installed. This camera took pictures during all sea ice flights, however, during the flights on April 13 and 16, the screen on the laptop supporting the camera did not work. A personal laptop was used to store the images, but due to the large amount of data, the images had to be transferred to an external HDD leaving some gaps in the data. For a more detailed description of images, see Section 5.8.

Table 5: Data acquisition overview, phase 1

Date	DOY	AIR1	AIR2	AIR3	AIR4	EGI	IMAR	ALS	ASIRAS	KAREN	GPS REF	Canon	Comments
18-03-2017	077	X	X	X	X	X	X	X	-	-	-	-	Test flight Problems with ASIRAS PC2
19-03-2017	078a	X	X[1]	X[1]	X	X	X[1]	X	LAMa[2]	-	-	-	
19-03-2017	078b	X	X	X	X	X	X[3]	X	LAMa	X	-	-	
20-03-2017	079a	X	X	X	X	X	X	X	LAMa	-	STN	X[4]	
20-03-2017	079b	X	X	X	X	X	X[1]	X	LAMa	-	STN	X[4]	
21-03-2017	080a	X	X	X	X	X	X	X	LAMa	X	STN	X[4]	
21-03-2017	080b	X	X	X	X	X	X	X	LAMa	X	STN	X[4]	
22-03-2017	081	X	-	-	X	X[5]	-	X	LAMa	X	-	X	
24-03-2017	083	X	X	X	X	X	X[6]	X	LAMa	X	YLT	X	
27-03-2017	086	X	X	X	X	X	X	X	LAMa	X	YLT	X	
28-03-2017	087	X	X	X	X	X	X	X	LAMa	X	-	X	
29-03-2017	088	X	X	X	X	X	X	X[7]	LAMa	X	-	X[8]	
30-03-2017	089A	X	X	X	X	X	X	X	X	X	-	X	
30-03-2017	089B	X	X	X	X	X	X	X	X		-	X	
31-03-2017	090A	X	X	X	X	X	X[9]	X	X	X	JQA	X	
31-03-2017	090B	X	X	X	X	X	X[9]	X	X	X	JQA	X	
01-04-2017	091A	X	X	X	X	X	X	X	X	X	-	-	

1) Started late
2) ASIRAS data only for calibration over runway CNP
3) Stopped 2.5 hours before landing
4) Partly coverage
5) Problems with GPS antenna cable. File size correct but no GPS signal so position not ok

6) Likely only small data gap
7) Not logging 15:54-16:35
8) Gap due to low battery 14:02-14:20
9) Not logging, full memory?

Table 6: Data acquisition overview, phase 2

Date	DOY	AIR1	AIR3	EGI H-764G	INS OxTS	ALS	KAREN	GPS REF	DSLR	Up	Down	SNIR	Log	Remarks
05-04-2017	95	-	-	-	X[6]	X	X	-	X	X	X			
07-04-2017	97A		-	X	X[6]	X	X	YCB	X	X	X		X	
07-04-2017	97B	X	-	X[1+2]	X	X	X	YCB	X	X	X		X	
08-04-2017	98	X	-	X[1]	X[6]	X	X	YCB	X	X	X		X	
11-04-2017	101	X	-	X	X	X	X	-	X	X	X		X	
12-04-2017	102A	X	-	X	X	X	X	-	X	X	X		X	
12-04-2017	102B	X	-	X	X	-	-	-	X	X	X		X	
13-04-2017	103	X	X	X	X[6]	X[3]	X	YLT	X[4]	X	X		X	
16-04-2017	106	X	X	X	X[6]	X	X	YLT	X[4]	X	X		X	
18-04-2017	108		X	X[5]	X	X	X	YLT	X	X	X		X	
19-04-2017	109	-	-	-	-	-	-	-	-	X	X	-	X	
20-04-2017	110A	X	X	X	X	X	-	-	-	X	X	-	X	
20-04-2017	110B	X	X	X	X	X	-	-	X	X	X		X	
21-04-2017	111	X	X	X	X[6]	X	-	-	-	X	X		X	
24-04-2017	114A	X	X	X	X	X	-	-	-	X	X		X	
24-04-2017	114B	X	X	X	X	X	X	-	X	X	X		X	
25-04-2017	115	X	X	X	X	X	X	LYR	-	X	X		X	Austfonna
26-04-2017	116	-	X	X	X	X	X	LYR	-	X	X		X	Austfonna

1) Not writing data after midnight to readegi.coo, but looks ok. PC dating issue 2003
2) In DASIN(dx) or ASIN(dx) or DACOS(dx) or ACOS(dx), DABS(dx).gt.1.0 (dx=-0.1683593620398824d+01). Error occurs at or near line 239 of _MAIN__
3) Wrong header format
4) Run on HSK personal laptop, some gaps due to data download
5) Four different files with various gaps in between. Main survey site only one gap
6) Something wrong with the OxTS xNav INS data. File size OK, but states in software it was not initialized properly

5 Processing

The data processing is shared between MetaSensing (MS), the Alfred Wegener Institute (AWI) and DTU Space. Both KAREN and ASIRAS data are processed using GPS and INS data supplied by DTU Space to ensure a consistent baseline, which is possible as all the instruments are flown on the same platform. GPS differential positioning and combined INS-GPS integration is performed at DTU Space followed by processing of laser distance measurement into elevation above a reference ellipsoid. The KAREN data is primarily processed by MS with input and expert knowledge from AWI. The ASIRAS data was processed by AWI using standard procedures.

The final data files are divided between the ESA CryoVEx and EU ICE-ARC projects. Links to the data is as follows:

- **CryoVEx flights (March 18-April 1 and April 12-26) can be requested at the ESA portal:** **https://earth.esa.int/web/guest/campaigns**
- **ICE-ARC flights (April 5-11) can be downloaded through:** **https://www.ice-arc.eu/data/**

5.1 GPS data processing

The exact position of the aircraft is found from kinematic solutions of the GPS data obtained by the GPS receivers installed in the aircraft, see Chapter 3. Two methods can be used for post-processing of GPS data, differential (DIF) processing and precise point positioning (PPP). Whereas the first method uses information from reference stations in the processing procedure, the PPP method is only based on precise information of satellite clock and orbit errors.

A Javad Maxor Receiver (REF1) with internal antenna and logging rate 1 Hz were used as temporary base station. The base station was mounted on DTU Space small tripods (vertical height 12 cm). However, the reference points were generally not marked, and thus the reference stations were not placed at the exact same position for the different flights, and a reference point has to be calculated for each flight. Permanent GPS reference stations have been used at some occasions where the base station is close to the flight route. This is the case for Scoresby Sund, Danmarkshavn, Station Nord, Thule AB, and Kelyville (Kangerlussuaq).

The positions of the temporary base stations are determined using the online GPS processing services AUSPOS (http://www.ga.gov.au/earth-monitoring/geodesy/auspos-online-gps-processing-service.html) offered by Geoscience Australia. The service calculates the position of the reference stations in the ITRF 2008 reference system using data from the closest permanent GPS stations with a position accuracy of about 2 cm. This accuracy is available even in the Arctic with long distances to the closest permanent stations. The coordinates of all the reference stations used during CryoVEx/ICE-ARC 2017 are found in Appendix 11.

The GPS processing was performed with Waypoint GrafNav (version 8.30 or 8.45) by use of precise IGS orbit and clock files and correction for ionospheric and tropospheric errors. For each flight several solutions are made using different combinations of GPS reference stations and aircraft receivers. The best solution for each flight is selected according to Table 7 and 8 and used in the further processing.

5.2 Inertial Navigation System

The position and attitude information (pitch, roll and heading) recovered from the INS instrument at 10 Hz, are merged with the GPS solutions by draping the INS derived positions onto the GPS solutions. The draping is done by modeling the function, found in the equation below, by a low pass smoothed correction curve, which is added to the INS.

$$\varepsilon (t) = P_{GPS}(t) - P_{INS}(t)$$

This way a smooth GPS-INS solution is obtained, which can be used for geolocation of laser and camera observations.

The selected INS solutions are listed in Table 7 and 8. As seen, most solutions are based on the primary Honeywell (H-764G) INS unit. Attitude information from the iMAR was used on flights March 19-21 during phase 1, due to issues with the GPS antenna setup supporting the Honeywell INS (see Section 4). The NovaTel was used as input for both GPS and INS solutions for flight on April 5, as this was the only instrument recording properly on this particular flight. Finally, attitudes obtained from OxTS Nav 550 were used in the processing of short sub-sections of the flight on April 18, due to gaps in the Honeywell data.

A comparison of the Honeywell and iMAR attitudes and scatterplots color-scaled according to time from flight March 28 is plotted in Figure 12 left and right, respectively. The Honeywell and iMAR aligns well, and show consistent high precision accuracy in all attitude components throughout the flight. This is consistent with a similar comparison during CryoVEx/KAREN 2016 presented in Skourup et al. (2018), supporting the conclusion that the iMAR solution is providing accuracy and precision similar to the Honeywell instrument.

A similar comparison of Honeywell and NovaTel attitudes in Skourup et al. (2018) showed that Honeywell and NovaTel roll angles compares well, except for a small off-set caused by the different installation configurations. However, both pitch and heading/yaw deviates by several degrees even at straight sections when compared to the Honeywell INS. Due to lack of data from Honeywell/OxTS and GPS units the flight on April 5 uses the NovaTel integrated GPS/INS solution as input. Only straight sections were used, corrected for offsets between solutions due to poor GPS absolute accuracy, see Section 5.3.

A prior version the OxTS Nav 550, the Inertial+2, has degraded accuracy during acceleration, which includes turns and rapid changes of altitude (Skourup et al., 2012). This could be the case also for the

OxTS Nav 550, however, as this unit was only used to patch in very short straight sub-sections of the flight on April 18, it is not expected to decrease the accuracy of this particular flight.

The best solutions of both GPS and INS data based on Table 7 and 8, is packed as binary files in the special ESA file format, see Cullen (2010). An overview of the final GPS and INS files is listed in Appendix 17 and 18 with file name convention according to Appendix 16.

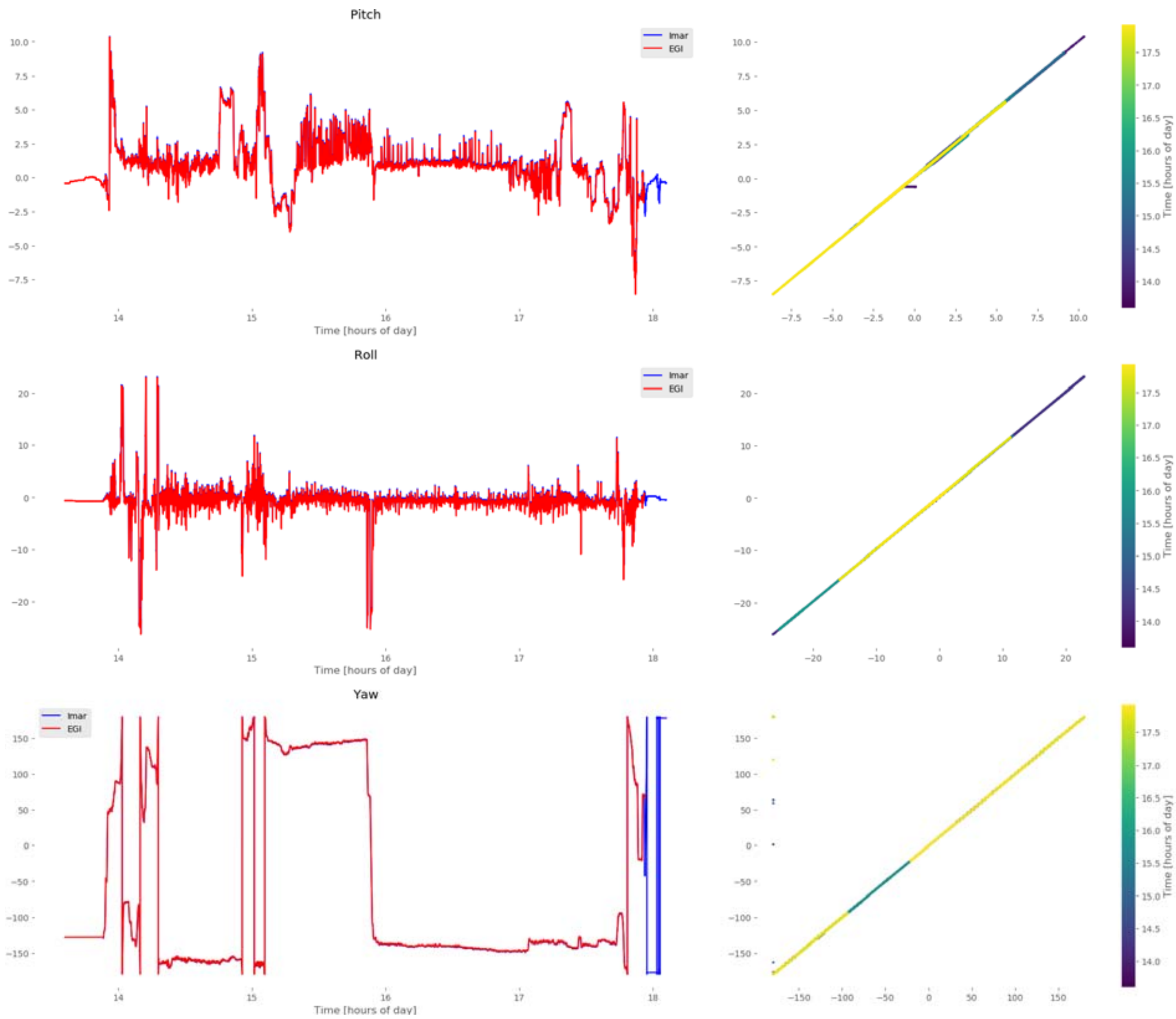

Figure 12: Inter-comparison of attitudes obtained by the Honewell (H-764G) and iMAR (RQH) INS. Flight out of CFS Alert April 28, 2017.

Table 7 List of best combination of GPS and INS data, phase 1

Date	DOY	GPS rover	Reference GPS	GPS processing	INS
18-03-2017	77	AIR2	-	PPP	H-764G
					H-764G
					H-764G
19-03-2017	78A + 78B	AIR4	SCOR	DIF	iMAR
20-03-2017	79A	AIR4	DMH	DIF	iMAR
20-03-2017	79B	AIR4	STN	DIF	iMAR
21-03-2017	80A	AIR4	REF1	DIF	iMAR
21-03-2017	80B	AIR4	REF1	DIF	iMAR
22-03-2017	81	AIR1	-	PPP	H-764G
					H-764G
					H-764G
24-03-2017	83	AIR4	REF1	DIF	H-764G
27-03-2017	86	AIR4	REF1	DIF	H-764G
28-03-2017	87	AIR4	THU2	DIF	H-764G
29-03-2017	88	AIR4	THU2	DIF	H-764G
30-03-2017	89A	AIR4	THU2	DIF	H-764G
30-03-2017	89B	No measurements			No measurements
31-03-2017	90A	AIR4	KELY	DIF	H-764G
31-03-2017	90B	AIR4	KELY	DIF	H-764G
					H-764G
01-04-2017	91A	AIR4	KELY	DIF	H-764G
					H-764G

Table 8 List of best combination of GPS and INS data, phase 2

Date	DOY	GPS rover	REF GPS	GPS pro.	INS
05-04-2017	95	NovaTel	-	PPP	NovaTel
07-04-2017	97A	AIR1	YCB1	DIF	H-764G
07-04-2017	97B	AIR1	YCB1	DIF	H-764G
08-04-2017	98	AIR1	YCB1	DIF	H-764G
11-04-2017	101	AIR1	-	PPP	H-764G
12-04-2017	102a	AIR1	-	PPP	H-764G
12-04-2017	102b	AIR1	-	PPP	H-764G
13-04-2017	103	AIR1	-	PPP	H-764G
16-04-2017	106	AIR3	YLT1	DIF	H-764G
18-04-2017	108	AIR3	YLT1	DIF	H-764G
		AIR3	YLT1	DIF	H-764G/OxTS
		AIR3	YLT1	DIF	H-764G
19-04-2017	109a	AIR1	-	PPP	H-764G
19-04-2017	109b	AIR1	-	PPP	No measurements
20-04-2017	110a	AIR3	-	PPP	H-764G
20-04-2017	110b	AIR1	-	PPP	H-764G
21-04-2017	111	AIR3	-	PPP	H-764G
24-04-2017	114a	AIR3	-	PPP	H-764G
24-04-2017	114b	AIR3	-	PPP	H-764G
25-04-2017	115	AIR1	LYR1	DIF	H-764G
26-04-2017	116	AIR3	LYR1	DIF	H-764G

5.3 Airborne Laser Scanner (ALS)

Both laser scanners are basically of the same type, using rotating mirrors, which results in parallel scan lines on the surface. The basic difference is that the LMS Q-240i-60 has 4 rotating mirrors each with a maximum scan-angle of 60˚, where the LMS Q-240i-80 has only 3 mirrors each with a scan-angle of 80˚. This results in a larger swath width with a lower resolution for the 3 mirror ALS. Both scanners operate with wavelength 904 nm, which is expected to reflect on the air-snow surface. The vertical accuracy is in the order of 10 cm depending primarily on uncertainties in the kinematic GPS-solutions. Further specifications of the two laser scanners are provided in Table 9. The raw logged files with start /stop times are listed in Appendix 12 and 13.

Table 9: Specifications of the two types of Riegl laser scanners

Scanner	Operating wavelength (nm)	Max scan angle	Resolution (m)	Swath-width (m)	PRF (Hz)	Number of measurements per scan-line
Riegl LMS-Q240i-60	904	60˚	0.7x0.7	300m	10,000	251
Riegl LMS-Q240i-80	904	80˚	1.0x1.0	400m	10,000	250

5.3.1 Calibration

Calibration of ALS misalignment angles between ALS and INS can be estimated from successive overflights from different directions of the same building, where the position of the corners is known with high precision from GPS measurements. For this purpose building overflights were performed in:

Phase 1:

- 20-03-2017 DOY 79 Station Nord
- 28-03-2017 DOY 87 CFS Alert

Phase 2:

- 13-04-2017 DOY 103 CFS Alert
- 25-04-2017 DOY 115 Longyearbyen

The ALS data has been routinely processed and the calibration angles for each flight based on the calibration flights together with inspection of cross-overs and overflights of relative flat surfaces can be found in Appendix 12-13 and Sections 5.3.3. An example of ALS elevations from overflight of the calibration building at Station Nord is given in Figure 13.

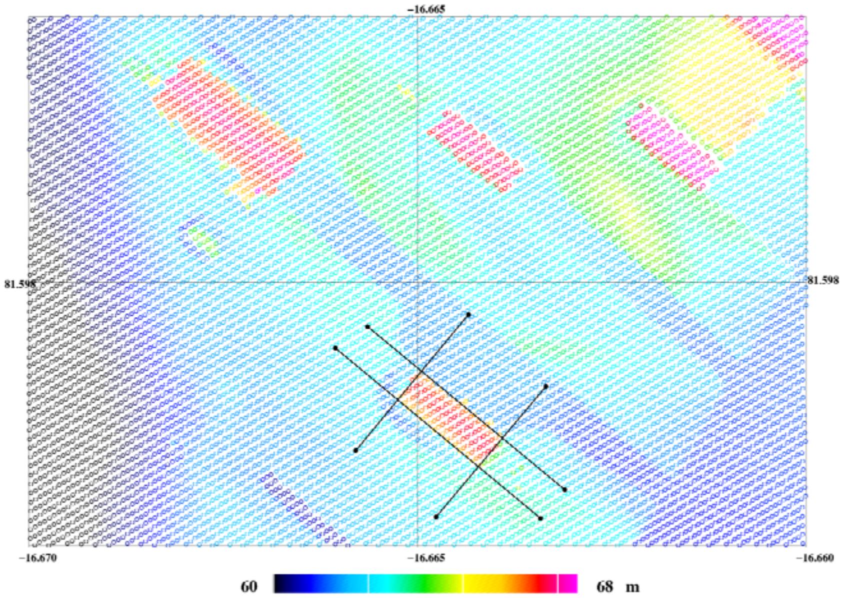

Figure 13: ALS elevations (w.r.t. WGS-84) of the calibration building (Ebbes Koldhal) at Station Nord.

5.3.2 Laser scanner outlier detection and removal

After an extensive service of the DTU Riegl ALS by the manufacturer (see Section 4) no issues were encountered with the neither the DTU nor the BAS instrument. Due to the tight installation of the instruments during Phase 1 multiple reflections from aircraft fuselage showed up as outliers in the ALS data. These outliers were filtered out in the final data set. The removal of outliers and clouds were done for both campaign phases by manual inspection of all data files using a python program (SkyFilt.py) with an option to automatically remove data points closer than a selected range (typically 50m) to the aircraft, by using input from processed GPS-heights and/or removal of a selected range window about the vertical elevation.

5.3.3 Cross-over Statistics

As a part of the processing routine, crossover statistics are derived for all repeated overflight within an hour of the first overflight. The quality of these crossover statistics varies depending on surface type, incidence angle and level of processing. In general statistics over sea ice is poor due to the drift of sea ice between inter-sections. The statistics based on raw scanner data after outlier editing are summarized in Table 10 and 11, and examples of cross-over differences over Devon ice cap and terrestrial flight near Cambridge Bay are given in Figure 14 and 15, respectively. The mean elevation differences in the cross-over points are less than 6 cm, and typically represent errors in the GPS solutions. The standard deviation of the cross-over differences is 6-10 cm over flat surfaces. These values are within the expected ranges and reflect data of high quality.

Table 10: Cross-over statistics, phase 1. Highlighted cross-overs are example provided in Figure 14.

Date	DOY	X-over	# points	Mean (m)	Std. Dev. (m)	Min. (m)	Max (m)	Notes
20170320		X0	24920	0.05	0.49	-0.54	0.23	Sea ice Fram Strait
		X1	40280	0.02	0.66	-3.72	4.16	Sea ice Fram Strait
20170321		X0	27688	0.04	0.24	-1.25	1.72	Sea ice, triangle
		X1	33683	0.02	0.39	-4.1	3.75	Sea ice, triangle
20170327		X0	10328	-0.05	0.35	-2.39	2.65	Sea ice, north of Alert
20170328		X0	28866	-0.02	0.06	-0.36	0.37	Greenland Ice Sheet
20170329		**X0**	**26121**	**-0.04**	**0.06**	**-0.43**	**0.37**	**Devon**
20170331		X0	34494	-0.01	0.10	-1.1	0.83	Baffin Bay sea ice
		X1	30268	0.04	0.10	-0.39	1.68	Greenland Ice Sheet
20170401		X0	31084	0.00	0.10	-3.19	3.3	Greenland Ice Sheet
		X1	28562	-0.06	0.09	-3.41	3.13	Greenland Ice Sheet

Table 11: Cross-over statistics, phase 2. Highlighted cross-overs are example provided in Figure 15.

Date	DOY	X-over	# points	Mean (m)	Std. Dev. (m)	Min. (m)	Max (m)	Notes
20170405	095	X0		0.01	0.10	-0.53	0.55	Landfast sea ice
20170407	097	X7	54002	-0.06	0.09	-0.49	0.38	Land
		X12	57602	-0.04	0.09	-0.63	0.42	Land
		X27	59421	-0.01	0.07	-0.37	0.43	Land
		X66	62441	0.03	0.07	-0.33	0.37	Land
		X87	66523	0.06	0.07	-0.31	0.38	Land
20170408	**098**	**X21**	**52153**	**0.02**	**0.06**	**-0.43**	**0.37**	**Land**
		X43	51235	-0.06	0.07	-0.36	0.33	Land
		X82	54207	0.00	0.07	-0.39	0.29	Land
		X90	81803	-0.03	0.06	-0.38	0.30	Land
		X101	52010	0.05	0.06	-0.35	0.35	Land
		X141	82381	0.03	0.06	-0.30	0.44	Land
20170413		X8	52676	-0.01	0.70	-8.09	7.51	Building CFS Alert
20170416		X1	16193	-0.01	0.36	-2.91	3.0	Sea ice
		X6	18131	-0.01	0.28	-2.33	2.59	Sea ice
20170418		X0	14534	0.01	0.24	-1.97	1.88	Sea ice
		X3	16078	-0.02	0.19	-1.21	1.73	Sea ice
		X15	16589	0.01	0.28	-2.56	2.13	Sea ice
20170426	116	X0	35633	0.03	0.09	-0.42	0.42	Austfonna

5.3.4 Final processed data

Processed ALS data comes as geo-located point clouds, in lines of width 200-300m at full resolution (1mx1m), in format time, latitude, longitude, heights given with respect to WGS-84 reference ellipsoid, amplitude and sequential number of data point per scan line (1-251). The dedicated

CryoVEx flights are packed in netcdf4 format, whereas the dedicated ICE-ARC flights are packed in DTU Space binary data format. An overview of the processed data is given in Figure 16 together with Appendix 19.

First flight in Cambridge Bay (April 5) was processed using the NovaTel GPS/INS solution (Table 8). As solutions using this unit (Section 5.2) are drifting during turns each of the 7 parallel lines have different roll offsets and different elevation offsets for each line as provided in Table 12. The elevation offsets have been estimated at 69.18°N in an area with level ice and the different lines have been adjusted to match line 3, hereafter referred to as "the reference ground track". The elevation offsets are within 9 cm of the reference ground track. Cross-over statistics of this flight is within the expected accuracy. Only straight sections (lines 1 to 7) are delivered with the elevation offsets applied, thus it is important to add similar elevation biases to KAREN elevation when compared to ALS data.

Table 12: Offsets applied to sub-tracks taken with respect to reference ground track (line 3) on flight April 5, 2017

Sub-track ID	Start time (UTC)	End time (UTC)	Roll offset	Elevation offset
1	21.561604	21.844099	-0.12	0.09
2	21.919705	22.149399	-0.12	0.01
3	**22.180901**	**22.432500**	**-0.14**	**0.00**
4	22.494907	22.714000	-0.16	-0.09
5	22.822203	23.027102	-0.16	-0.06
6	23.097902	23.318799	-0.14	0.02
7	23.374002	23.576295	-0.14	-0.08

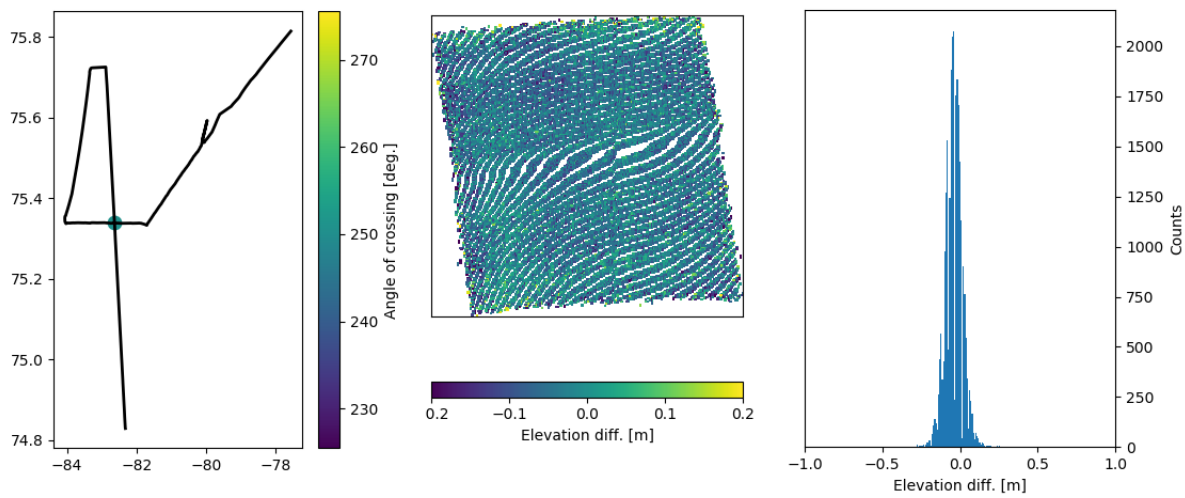

Figure 14: Location of cross-over point at Devon ice cap (left), ALS cross-over elevation differences (middle and right) from flight March 29, 2017.

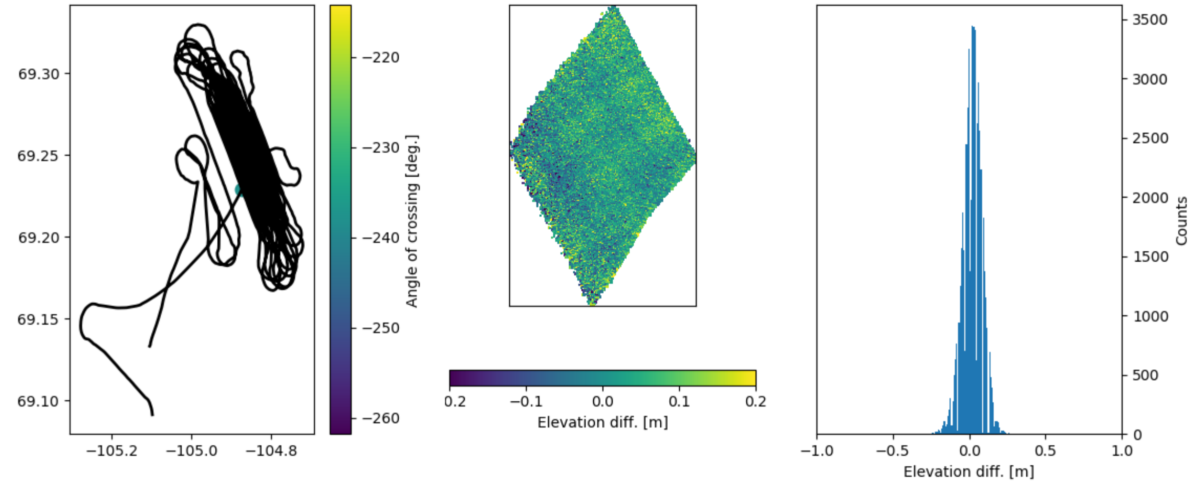

Figure 15: Location of cross-over point over land near Cambridge Bay (left), ALS cross-over elevation differences (middle and right) from flight April 8, 2017.

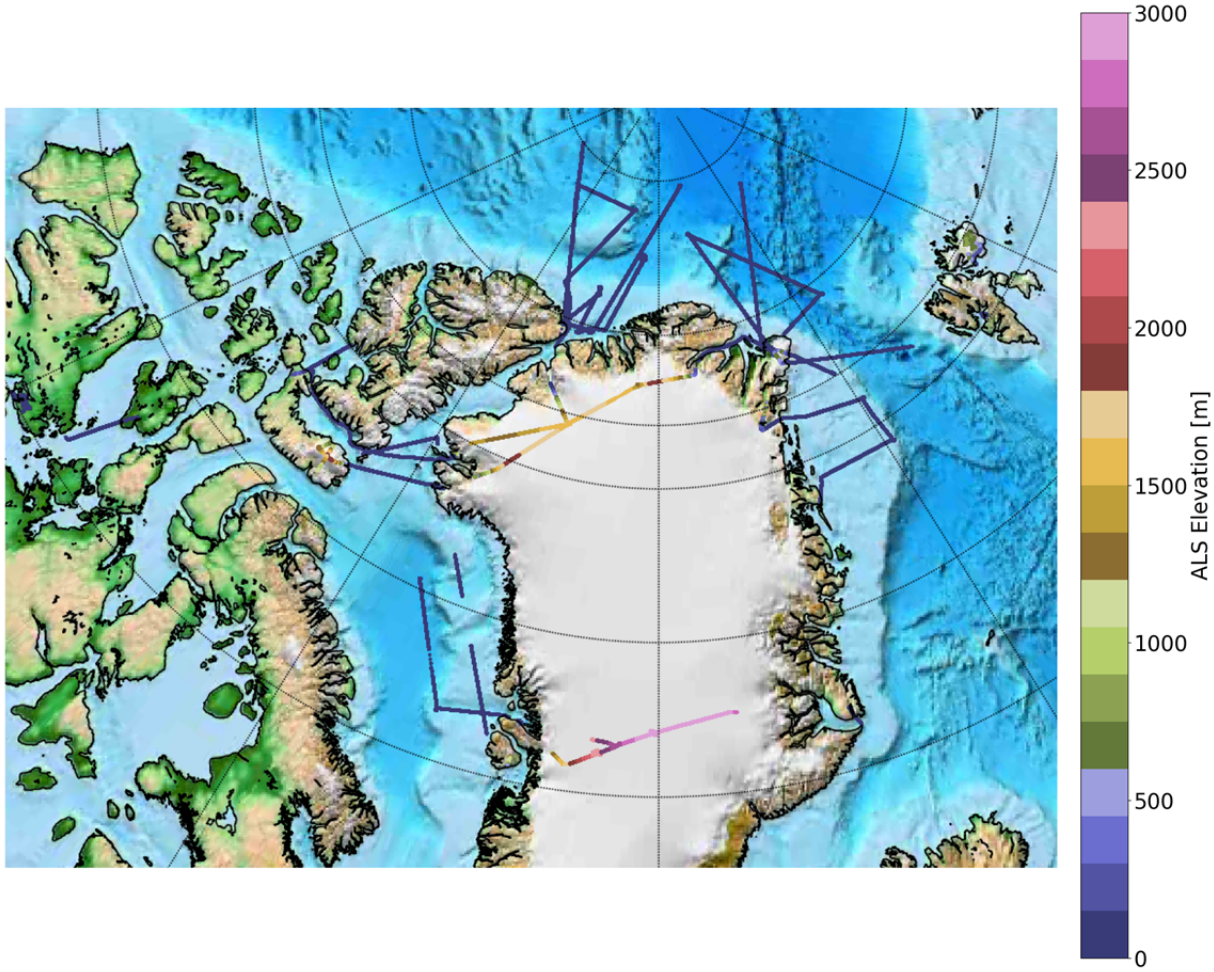

Figure 16: Mission overview of the processed ALS data. All recorded heights are given as geo-located point-

clouds with respect to the WGS-84 reference ellipsoid.

5.4 ASIRAS

The ASIRAS radar operates at 13.5 GHz with footprint size 10 m across-track and 3 m along-track at a standard flight height of 300 m. The range resolution for ASIRAS is 0.1098m. ASIRAS specifications are provided in Table 13. An overview of the acquired ASIRAS log-files together with start/stop times, range window and number of pulses are listed in Appendix 14.

5.4.1 Processing

The ASIRAS processing of the raw (level 0) data files is analogous to the concepts already presented in Helm et al. (2006), using ESA's processor version ASIRAS_04_03. The processed ASIRAS data is delivered as a level-1b product in the ESA binary format as described in Cullen (2010). The product includes full waveform information, and an estimate of the retracked height w.r.t. WGS-84 reference ellipsoid using a simple Offset Center of Gravity (OCOG) retracker, together with information about aircraft attitude.

The OCOG retracker was developed to give a quick and rough estimate of surface elevation and not to be as precise as possible. It may not be the optimal retracker in areas with several layers in the snow/firn, e.g. the perculation zone on ice sheets, see e.g. Helm et al. (2006) and Stenseng et al. (2007), and it is up to the user of the data to apply different retracker algorithms depending on the application. Roll angles are given as part of the attitude information, as it is common to remove roll angles above/below a certain threshold (±1.5°) due to waveform blurring.

To get absolute heights, it is crucial for the user to perform a runway calibration to estimate an off-set due to internal loss in the radar system and to apply the off-set to all retracked data. As the off-set is dependent on the choice of retracker the runway calibration shall be performed using the same retracker as used for the scientific application. To validate the ASIRAS data quality an example of the runway calibration using a simple OCOG retracker is given in Section 5.6.

5.4.2 Final processed data

The final processed ASIRAS level-1b data is delivered in the special ESA format as defined in Cullen (2010). A list of final level-1b files is available in Appendix 22 and a summary of the processing is given in Appendix 23 together with plots of each profile.

Table 13: Specifications of ASIRAS and KAREN at 300m flight altitude above the surface

Instrument	Frequecy (GHz)	Footprint size		Range resolution (m)
		Along-track (m)	Across-track (m)	
ASIRAS	13.5	3	10	0.1098
KAREN	34.525	5	12	0.1650

5.5 KAREN

The KAREN airborne instrument is an interferometric frequency modulated continuous wave (FMCW) SAR altimeter working at the Ka-band with central frequency of 34.525 GHz. The sensor operates with FMCW radar modulation in interferometric mode (SARIn), with one transmitting antenna and two receiving antennas. These are patch antennas, as opposed to the CryoVEx/KAREN 2016 fall campaign where horn antennas were used. Radiation characteristics of the new patch antennas include a gain of 22 dBi and a 3dB aperture of 15° x 4.6° (along track and cross track). The processed multi-looked data corresponds to an along- and across-track footprint size of 5 m (100 looks) and 12 m, respectively. The vertical resolution is 0.1650 m. KAREN specifics are provided in Table 13. An overview of the acquired data is provided in Appendix 15. The name of each file represents the date and starting time of the acquisition. For each acquisition the file size and some additional notes are given, such as duration of acquisition, altitude of the aircraft during the acquisition and area of interest.

5.5.1 Processing

There have been several iterations of the processing, as described below:

vvvv	First version combining both channels (May 2018)
hamh	Hamming filtering applied (July 2018)
leva	Leverarms applied, but geographic longitude “jumps” when entering a new UTM-zone
levb	Final product as described below (November 2018)

The final version “levb” processing chain is similar to ASIRAS in High Altitude Mode (HAM) and introduces several steps going from the raw data format (level-0) to the final delivered data format (level 1B), including range compression (FFT and Hamming filtering), zero-Doppler filtering, ground-back projection (GBP), and multi-looking. For a more detailed description see the “KAREN altimeter - Processing chain and file format” documentation (MS-DTU-KAR-03-PFF-030). During the processing chain each KAREN data point is geo-located using input from best solutions of GPS and INS data provided by DTU units according to Table 7 and 8, and corrected for lever-arms between GPS antenna and KAREN reference points provided in Table 3 and 4 for respective campaign phases. All examples in this report are based on version “levb”, unless otherwise stated.

Several plots generated in-flight during acquisitions for quick-data analysis purposes are shown in Figure 17-21. A detailed example of Range Doppler map is shown in Figure 17, processed from data acquired during the 1st of April 2017 with in situ Twin Otter aircraft visible in Range Doppler map about (360m, -40km/h), Figure 18 and 19. In Figure 20 an iceberg is shown in the Range-Doppler maps of the two channels, and relative interferometric phase. The corresponding range compressed image is shown in Figure 21.

To get absolute heights, as in the case for ASIRAS (see Section 5.4.1) **it is crucial for the user to perform a runway calibration to estimate an off-set due to internal loss in the radar system and to apply the estimated off-set to all retracked data. As the offset is dependent on the choice of retracker the runway calibration shall be performed using the same retracker as used for the specific scientific application.** To validate the performance and quality of the KAREN data an example of the runway calibration using a simple OCOG retracker is given in Section 5.6. The user should also be aware of waveform blurring for large roll-angles. For ASIRAS data with roll angles below -1.5° and above a +1.5° is discarded. These thresholds are used for KAREN runway calibration in Section 5.6, but another threshold might apply to KAREN.

5.5.2 Final packed data

The final data is packed in netcdf format and includes position and attitude of each measurement, full waveform information, as well as phase and coherence from the use of dual antennas in the interferometric mode. The retracking is left to the user, as the choice of retracker depends on user requirements. An overview of the final data is provided in Appendix 21.

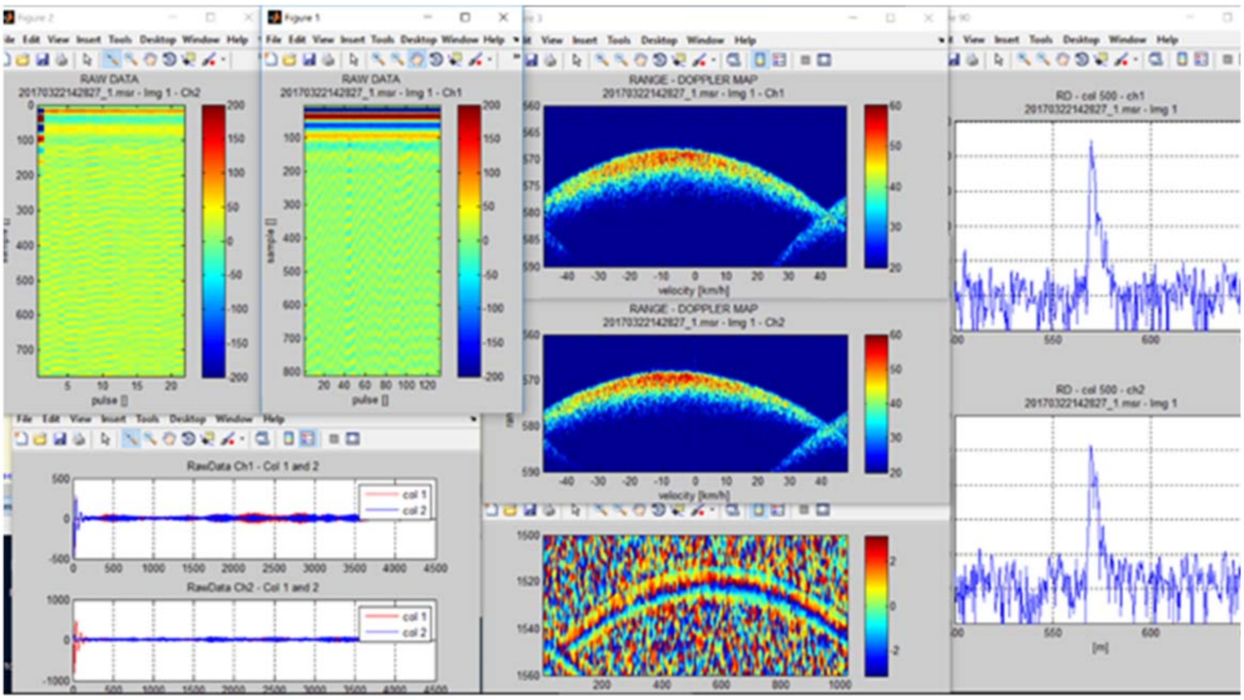

Figure 17: Plots generated during flight for quick check: data acquired on the 2nd of March 2017.

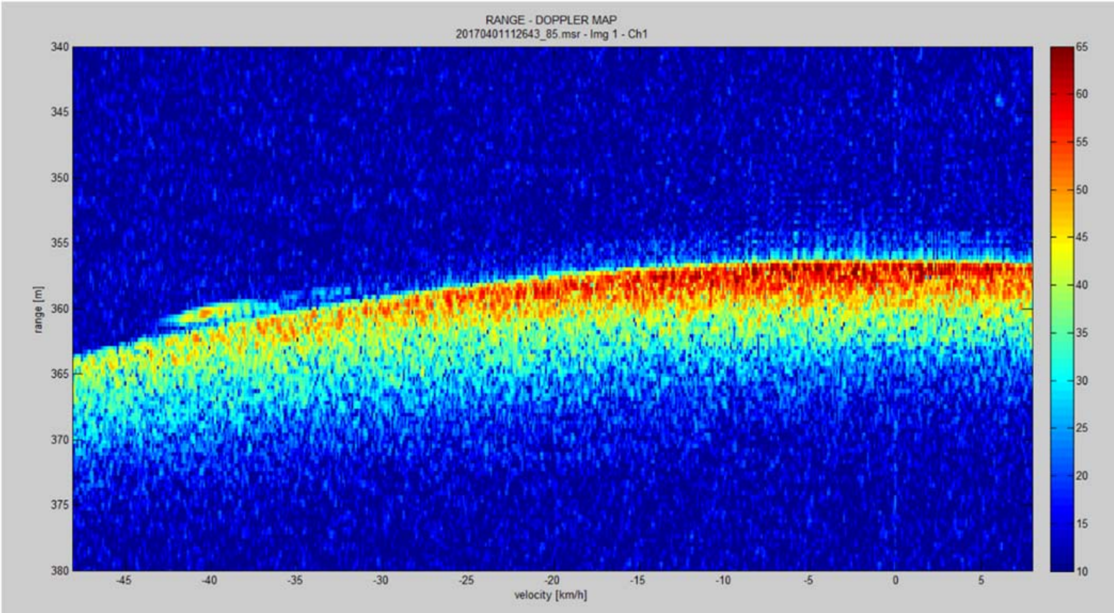

Figure 18: Example of Range-Doppler map from data acquired on April 1, 2017.


Figure 19: Picture of validation team at the EGIG-line acquired during flight on April 1, 2017.

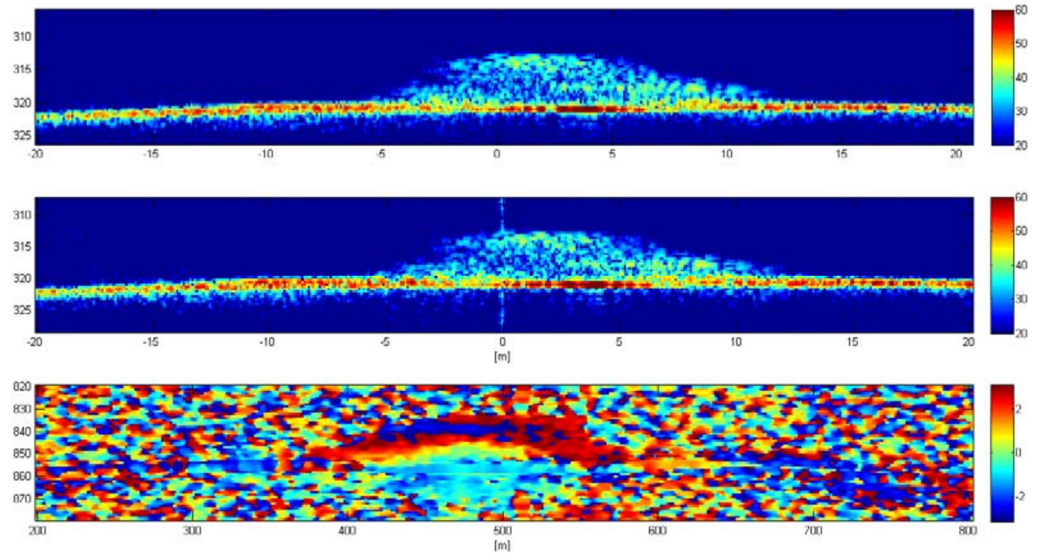

Figure 20: RD maps for the 2 channels and interferometric phase of data acquired on March 30, 2017.

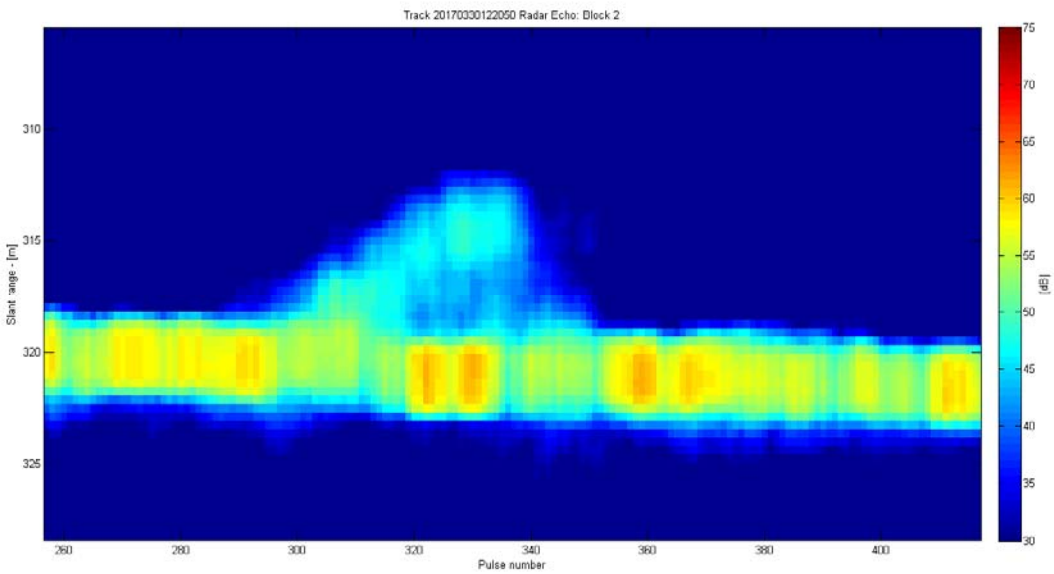

Figure 21: Example of a Range compressed image acquired on March 30, 2017, see Figure 20.

5.6 Calibration and absolute heights of ASIRAS and KAREN

To obtain absolute surface heights from ASIRAS and KAREN an offset needs to be applied to account for internal delays in cables and electronics, see Sections 5.4.1 and 5.5.1. As the offset is dependent on the choice of retracker it has not been applied in the final Level 1b processing. The offset is estimated by comparing ASIRAS and KAREN surface heights to surface heights obtained by ALS over a surface, where both the radar and the laser are known to reflect at the same surface. Such measurements are typically obtained by overflights of runways. Different biases apply for the different aircraft installations, see Section 3.

The runway overflights performed during CryoVEx/ICE-ARC 2017 campaign is listed below:

Phase 1:

- 19-03-2017 DOY 78 Constable Point
- 28-03-2017 DOY 87 CFS Alert
- 31-03-2017 DOY 90 Qaarsut

Phase 2:

- 08-04-2017 DOY 98 Cambridge Bay
- 13-04-2017 DOY 103 CFS Alert
- 25-04-2017 DOY 115 Longyearbyen

The data from the runway overflights are available in the delivered data set.

In the following we compare ALS surface elevations with OCOG retracked elevations from ASIRAS and KAREN. All radar elevations with roll angles below/above -1.5/1.5, has been discarded due to waveform blurring. For each ASIRAS and KAREN elevation we use a search radius of 3m and 5m, for ASIRAS and KAREN, respectively, corresponding to 4-5 ALS elevations to account for the extent of the footprint size of the radar systems. The ALS elevations within the search radii are averaged and subtracted from the radar elevation. A total mean is given for each runway overflight representing the off-set provided in Tables 14-16. In addition standard deviation and percentage of accepted points due to the limits on roll are also provided.

In phase 1 runway overflights in Qaarsut (JQA) and CFS Alert (YLT) have offsets within 3 cm for ASIRAS and 9 cm for KAREN, with slightly larger standard deviation of the KAREN data 10-11 cm compared to ASIRAS 5-9 cm.

The best estimate of offsets during phase 1 is from March 31 first overflight in Qaarsut using the OCOG (TRMFA 50%) retracker is 3.64 m (3.83 m) for ASIRAS and 0.07 m (0.08) for KAREN (marked by red in Table 14 and 15). This overflight was selected as the best runway overflight as both radar and ALS elevations are coincident in time. In phase 2 best estimated offset for OCOG (TRMFA 50%) retracked KAREN is 0.12 m (0.13) based on second runway overflight in Longyearbyen on April 25 (marked by red in Table 16). These off-sets have to be applied to all OCOG-re-tracked ASIRAS and KAREN elevations prior to any analysis using absolute heights.

The first runway overflight on March 31 is visualized in Figure 22 and 23. The along-track comparison of the ALS surface elevations (blue) and the ASIRAS OCOG retracked elevations (red) is shown in Figure 22 top left, together with aircraft roll-angles (black) and pitch (gray) in lower left. The statistical distribution of the differences between the ALS elevations and KAREN and ASIRAS are shown in the histogram (top right).

As seen in Tables 14-16, the offsets depend on the chosen retracker. It is also seen that the KAREN data is more noisy (larger standard deviation) when compared to ASIRAS. This is primarily due to the lower number of looks used in the KAREN (100) processing, than in the ASIRAS (400) processing. If the KAREN processing is changed to include more looks in the processing the along-track resolution would be compromised. Thus, by including 400 looks the noise would decrease, but the along-track resolution would be about 4 times as large ~20 m, due to the lower bandwidth of KAREN compared to ASIRAS.

In this section, the offset between the ASIRAS and ALS surface heights are found, using the OCOG and TRMFA 50% retracked surface elevations. Similar procedures have to be applied by the user of the ASIRAS data when using other retrackers.

Table 14: ASIRAS offsets (ALS-ASIRAS) over runways, phase 1

						OCOG		TRMFA 50%		
Profile	Site	Overflight	Start time UTC	End time UTC	# points	Off-set (m)	Std (m)	Off-set (m)	Std (m)	Roll (%)
A20170319_01	CNP	1/comp	41141	41153	370	4.49	0.96			81
A20170328_00	YLT	2/2	-	-	-	-	-			0
A20170328_00	YLT	3/2	51109	51119	303	3.65	0.09			61
A20170331_02	**JQA**	1/1	**61489**	**61495**	**218**	**3.64**	**0.06**	**3.83**	**0.04**	**47**
A20170331_02	**JQA**	2/1	**61721**	**61731**	**281**	**3.62**	**0.05**			**64**

Table 15: KAREN offsets (ALS-KAREN) over runways, phase 1

						OCOG		TRMFA 50%		
Profile	Site	Overflight	Start time	End time	# points	Off-set (m)	Std (m)	Off-set (m)	Std (m)	Roll (%)
KA20170319_112530	CNP	1/comp	41141	41153	165	0.65	0.78	0.63	1.00	81
KA20170328_140607	YLT	2/2	-	-	-	-	-			0
KA20170328_141101	YLT	3/2	51109	51120	133	-0.02	0.11	-0.01	0.12	62
KA20170331_170431	**JQA**	1/1	**61489**	**61496**	**95**	**0.07**	**0.10**	**+0.08**	**0.12**	**46**
KA20170331_170802	**JQA**	2/1	**61721**	**61731**	**128**	**0.04**	**0.10**	**+0.04**	**0.13**	**63**

Table 16: KAREN offsets (ALS-KAREN) over runways, phase 2

						OCOG		TRMFA 50%		
Profile	Site	Overflight	Start time	End time	# points	Off-set (m)	Std (m)	Off-set (m)	Std (m)	Roll (%)
KA20170409_013236	YCB	1/1	5963	5987	258	0.16	0.09	0.16	0.09	80
KA20170413_190833	YLT	1/1	69167	69187	249	1.37	5.27	1.63	5.88	100
KA20170413_192741	YLT	2/1	70250	70278	211	0.16	0.04	0.16	0.05	59
KA20170425_115656	LYR	1/2	43152	43190	187	0.24	0.07	0.25	0.07	38
KA20170425_115656	**LYR**	**2/2**	**43398**	**43434**	**322**	**0.12**	**0.08**	**0.13**	**0.08**	**70**

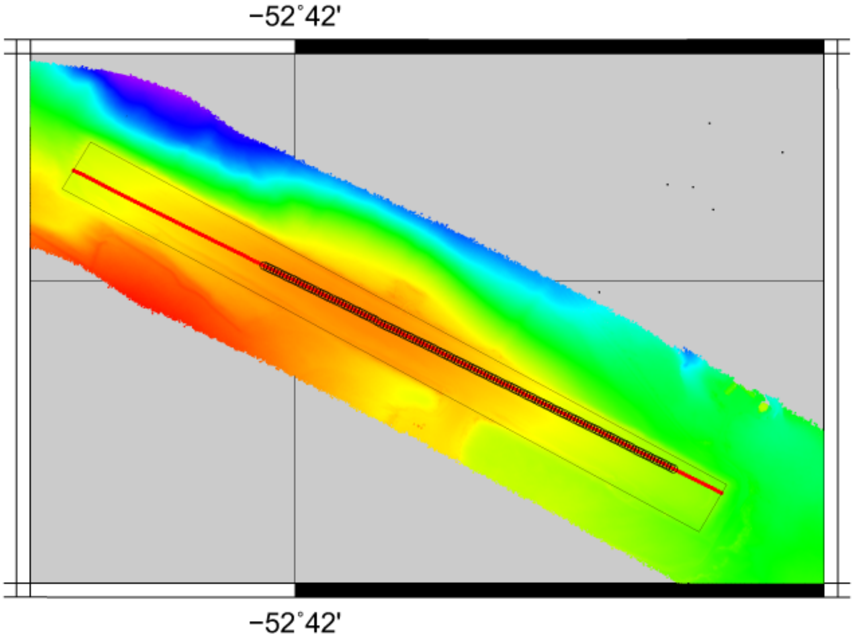

Figure 22: ALS elevations model (w.r.t WGS-84) of runway in Qaarsut, March 31, 2017.

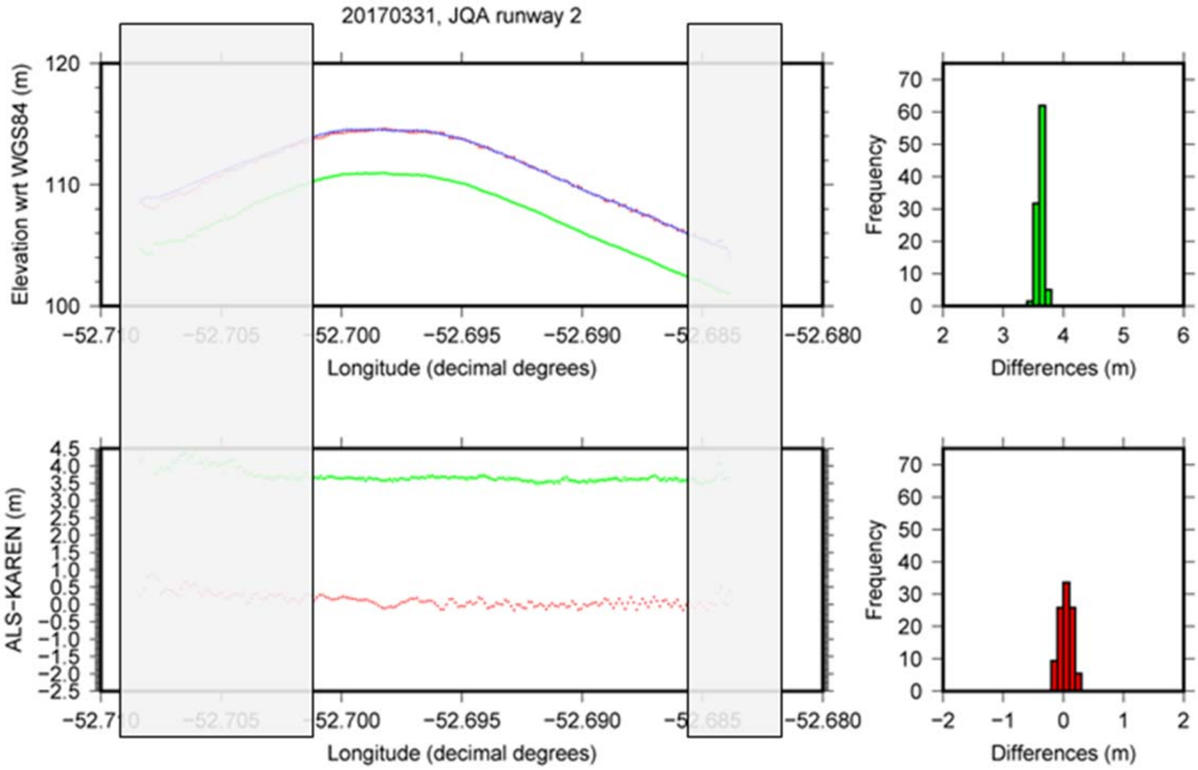

Figure 23: Comparison of ALS, KAREN and ASIRAS elevations over runway in Qaarsut, March 31, 2017 (1st overflight). ALS (blue), KAREN (red) and ASIRAS (green) elevations (top left). Differences between ALS-KAREN (red) and ALS-ASIRAS (green) are shown with related histograms of ALS-ASIRAS (top right) and ALS-KAREN (bottom right). The gray areas mark parts of the flight where data has been discarded due to large roll.

5.7 Horizontal alignment between ASIRAS and KAREN

In order to compare results from ASIRAS and KAREN it is important that the two systems are aligned. The locations of the ASIRAS and the KAREN data are referred to their own reference points. ASIRAS reference point is centered at the aft of the ASIRAS antenna, whereas KAREN reference point is located at the center point between the receiving (aft) antennas. The differences between the ASIRAS and KAREN reference points for the different phases are:

Phase 1 (OY-POF): dx=+0.34m, dy=+0.00m, dz=+0.185m

Phase 2 (VP-FAZ): dx=+0.98m, dy=+0.07m, dz=+0.240m

taken with respect to the aircraft coordinate system as outlined in Figure 3.

In previous CryoVEx campaigns corner reflectors have acted as point targets. If the exact positions of these are known, the radar data can be time-tagged and thus aligned in the along-track direction. Small metal plates placed directly on the snow are in general difficult to locate in the radar waveforms and the locations are not known. The location of the corner reflectors located at Devon ice cap was known with high precision (see Table 17), but these were covered in snow (see Figure 24), and by first look, it has been impossible to identify reflections from these in the processed radar data.

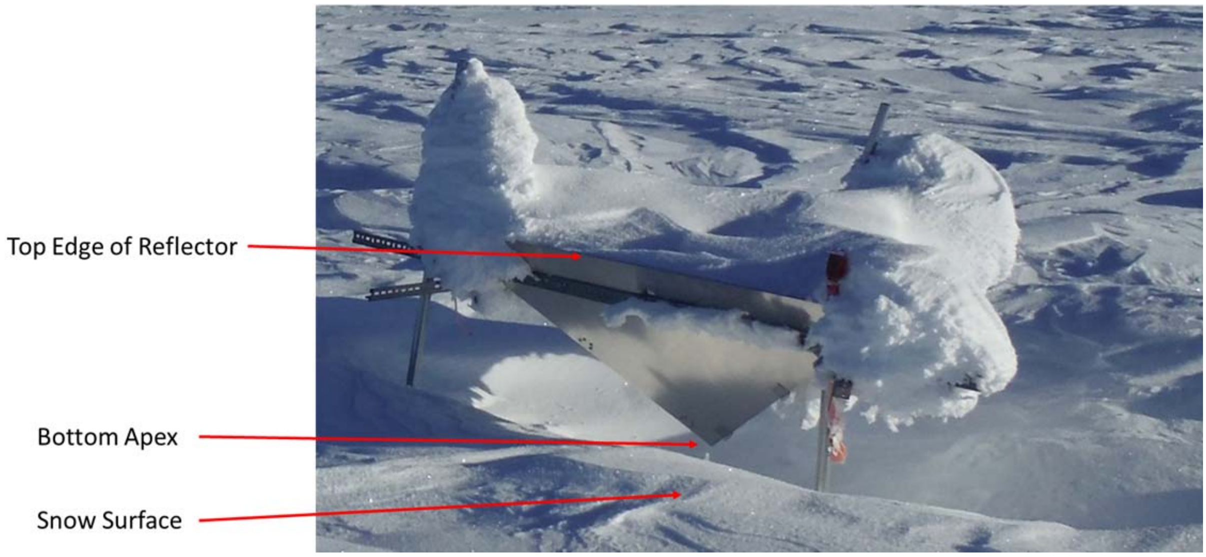

Figure 24: Photo of corner reflector at Devon ice cap covered in snow by courtesy: D. Burgess, Natural Resources Canada

Table 17: Location of corner reflectors at Devon ice cap (Courtesy: D. Burgess, Natural Resources Canada)

CR	Lat	Lon	Ell_Ant Height(m)	AntHeight Error(m)	Ant Vert Offset (Ant-TopEdge m)	TopEdgeRefl	BottApex OffsetfromTopEdge	BottApex	BottApexToSnowSurface	Snow Surface (m)
East	75° 20' 16.82268''	-82° 40' 39.55078 ''	1796.875	0.002	0.56	1796.315	0.72	1795.595	-0.44	1796.035
Mid	75° 20' 17.5192''	-82° 40' 41.5086''	1796.949	0.012	0.21	1796.739	0.64	1796.099	-0.34	1796.439
West	75° 20' 18.3772''	-82° 40' 43.91433 ''	1797.048	0.002	0.27	1796.778	0.69	1796.088	-0.47	1796.558

5.8 Camera

To complement the analysis of KAREN, ASIRAS and ALS data over sea ice high resolution images are collected along the flights. During phase 1 slant looking images were obtained using a camera of type Canon 60D. The camera was mounted in the rear window in the cabin using a Fat Gecko camera mount. To optimize the contrast of the images, the camera was mounted either in starboard or port side of the aircraft depending on the sun angle. During phase 2 a nadir-looking high resolution DSLR camera was used. An overview of the properties of the cameras is given in Table 18 and examples are shown in Figure 25-26. Both cameras were remotely controlled and time tagged using the internal camera clock. By combining the time tag of the images with GPS data the images has be geo-located along the flight lines. Positions of each image are given in a position file, and the raw images are packed in zip-files of about 2 MB (see overview Appendix 20).

Table 18: Overview of camera types and settings.

Camera type	View	Interval (sec)	Resolution (pixels)	Image size (MB)	Software program	Format
Canon 60D	Slant-looking	12	2592x1728	~0.5	DSLR Remote Pro 232	JPEG
Canon EOS 7D	Nadir-looking	5	5184x3456	~27	EOS Utility	RAW

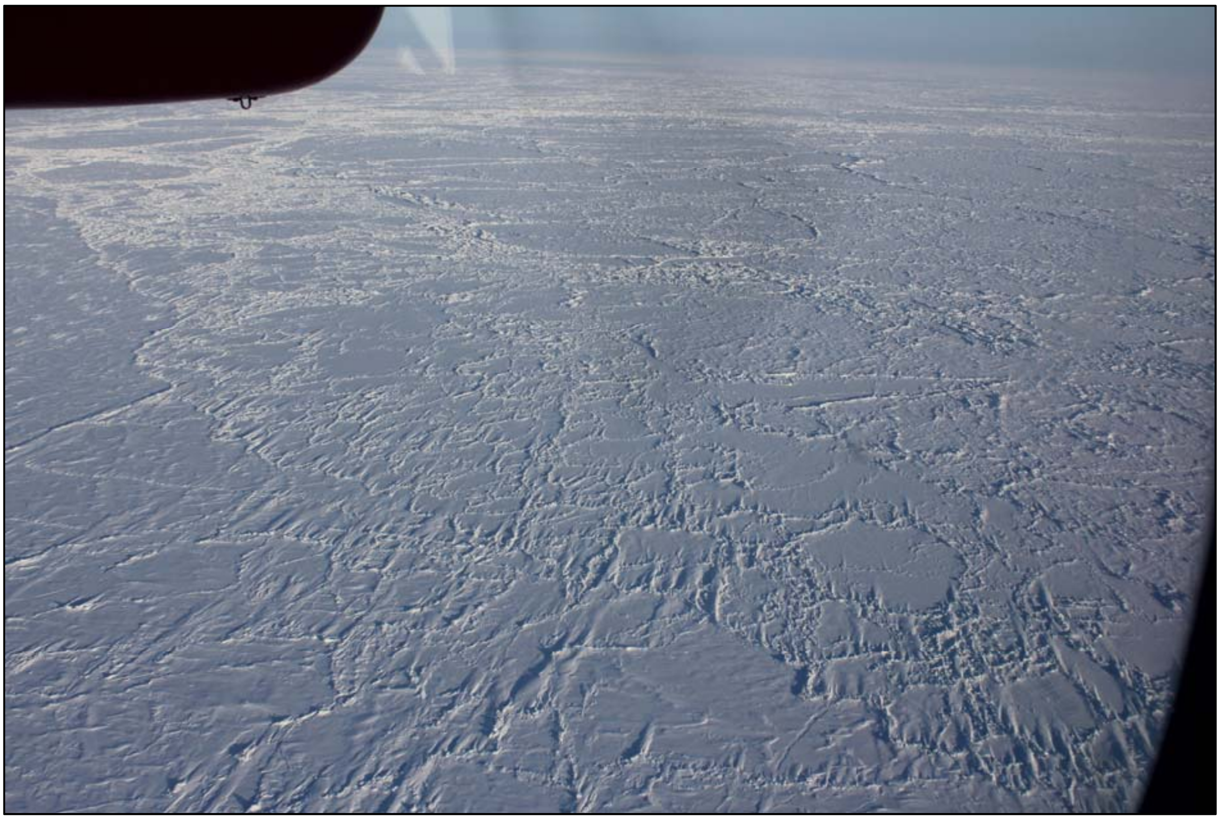

Figure 25: Examples of slant-looking image (0031) taking during phase 1 on flight March 24, 2017.

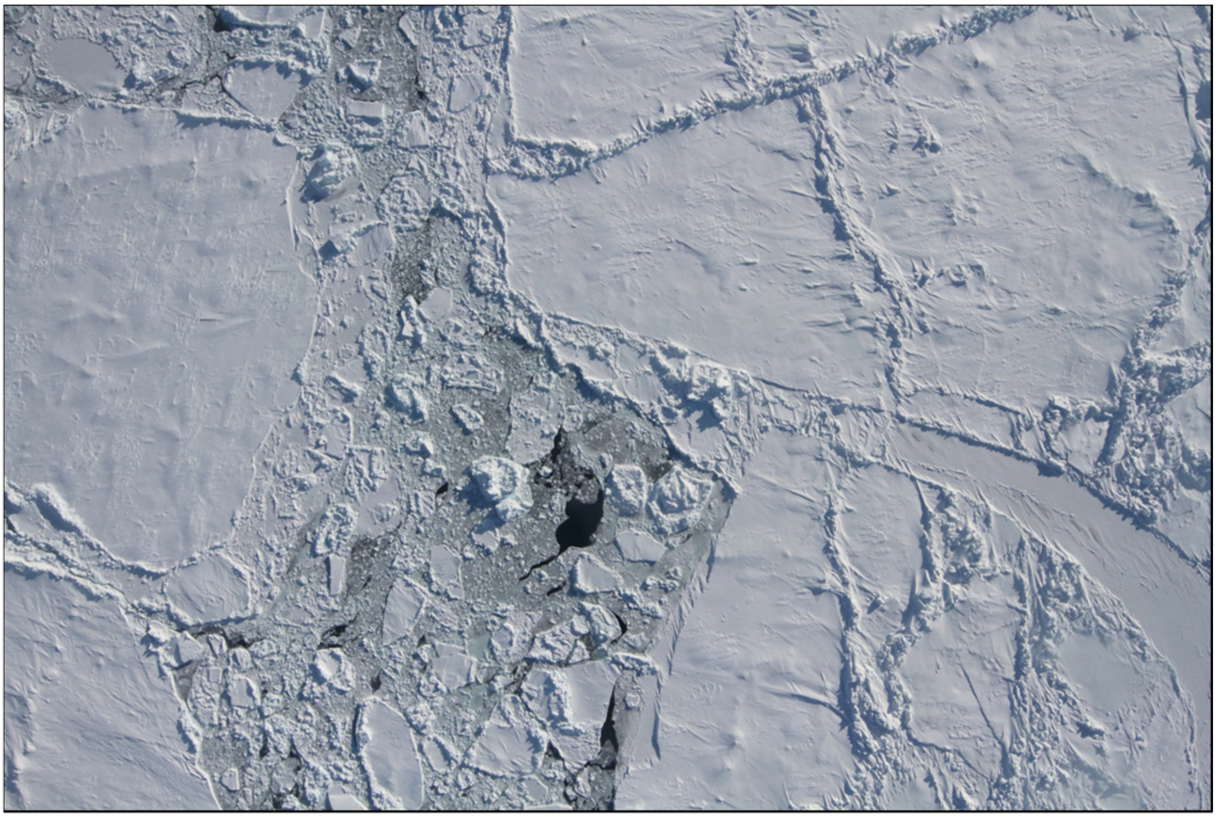

Figure 26: Examples of nadir-looking camera during phase 2. It is mounted with the wide image dimension in the along-track direction permitting overlapping images even at a relative low acquisition rate of 0.2 Hz

6 Calibration and Validation sites

During the CryoVEx/KAREN 2017 campaign, several radar altimeter ground tracks were flown, including several CryoSat-2 orbits, Sentinel-3A and for the first time SARAL/AltiKa. Some of these were coordinated with in situ work. All airborne and coordinated in situ data acquisitions along CryoSat-2, Sentinel-3 and SARAL/AltiKa ground tracks are listed in Table 19, together with information of orbit numbers and passage times. Table 19 includes primarily sea ice flights, where timing is crucial due to the drift of the ice. No land ice flights were following near-real time satellite ground tracks, but crosses several CS-2, Sentinel-3 and SARAL/AltiKa ground tracks. In the following Sections the main calibration and validation sites are provided, together with first results, over sea ice (section 6.1), land ice (section 6.2) and land (section 6.3).

6.1 Sea Ice

In total, five CryoSat-2, two SARAL/AltiKa and two Sentinel-3 underflights were performed over sea ice (Figure 1 and Table 19) in different regions representing different sea ice types and conditions.

For satellite underflights timing is crucial especially over drifting sea ice. This was challenging due to limited opening hours of the airports. To account for the ice drift between data acquisition of flights and CryoSat-2 passages, most of the tracks were measured twice. In addition, information of the sea ice conditions and drift was kindly prepared during the field campaign from repeated SAR images from Sentinel 1a and 1b and distributed to the involved field teams by R. Saldo (DTU Space). An example of a Sentinel-1 SAR image covering the Fram Strait, together with drift information and satellite orbit ground tracks from SARAL/AltiKa kindly provided by A. Guillot (CNES) can be seen in Figure 27. Such information provides invaluable information to the field team. None or the less, most flights are flown within few hours of satellite passage time see Table 19.

In the following Subsections the flights are described in more details. This yields in particular the work made out of CFS Alert (Section 6.1.1) with focus on the comparison of airborne measurements and in situ observations (Section 6.1.2 and 6.1.3). An overview of the first underflights of SARAL/AltiKa and description of coincident in situ work out of CamBay SnowExp 2017 (Section 6.1.4), and Sentinel-3A (Section 6.1.5), but also describes first results of overflight of NPI moored upward looking sonars in Fram Strait which has been done repeatedly since 2005 (Section 6.1.6). Additional work, including CryoSat-2 ALS swath-flight, overflight of shear zone, and additional data sources is provided in Section 6.1.7.

Table 19: Overview of airborne data acquisitions along CryoSat-2, Sentinel-3 and SARAL/AltiKa ground tracks, together with information of orbit numbers, passage time, and data acquisition.

Sea ice	Land ice	Location	Airborne Activity	Satellite	Orbit #	passage Date and time (Time given as hh:mm UTC)	ASIRAS	KAREN	ALS	AWI-AEM	NASA OIB	NASA GLISTIN	In Situ
X		Fram Strait	20-03-2017	SARAL/AltiKa[1]	387 cycle 107	20-03-2017 02:25	X	X	X				
X		Wandel Sea	21-03-2017	CryoSat-2	36847	21-03-2017 14:15	X	X	X				
X		Lincoln Sea	24-03-2017	CryoSat-2	36892	24-03-2017 16:40	X	X	X				
X		Lincoln Sea	27-03-2017	CryoSat-2	36936	27-03-2017 17:27	X	X	X	X	X	X	X[2]
X		Lincoln Sea	27-03-2017	CryoSat-2	37159	12-04-2017 02:11	X	X	X				X[2]
X		Baffin Bay	29-03-2017	Sentinel-3A		29-03-2017 17:47	X	X	X				
X		Baffin Bay	31-03-2017	SARAL/AltiKa	709 cycle 107	31-03-2017 08:21	X	X	X				
X[3]		Dease Strait	05-04-2017	SARAL/AltiKa	846 cycle 107	05-04-2017 02:33		X	X				X
X		Lincoln Sea	13-04-2017	CryoSat-2	37159	12-04-2017 02:11		X	X		X[4]		X
X		Lincoln Sea (MOW)	16-04-2017	CryoSat-2	37255	16-04-2017 15:23		X	X				
X		Lincoln Sea	16-04-2017	CryoSat-2	36892	24-03-2017 16:40		X	X				X
X		Fram Strait	24-04-2017	Sentinel-3A		24-04-2017 18:09		X	X				

1) Not following the exact SARAL/AltiKa track, but covering a large easy to re-track sea ice floe …
2) In situ work in phase 2
3) Partly sea ice and partly snow on land
4) Flown on April 11, 2017

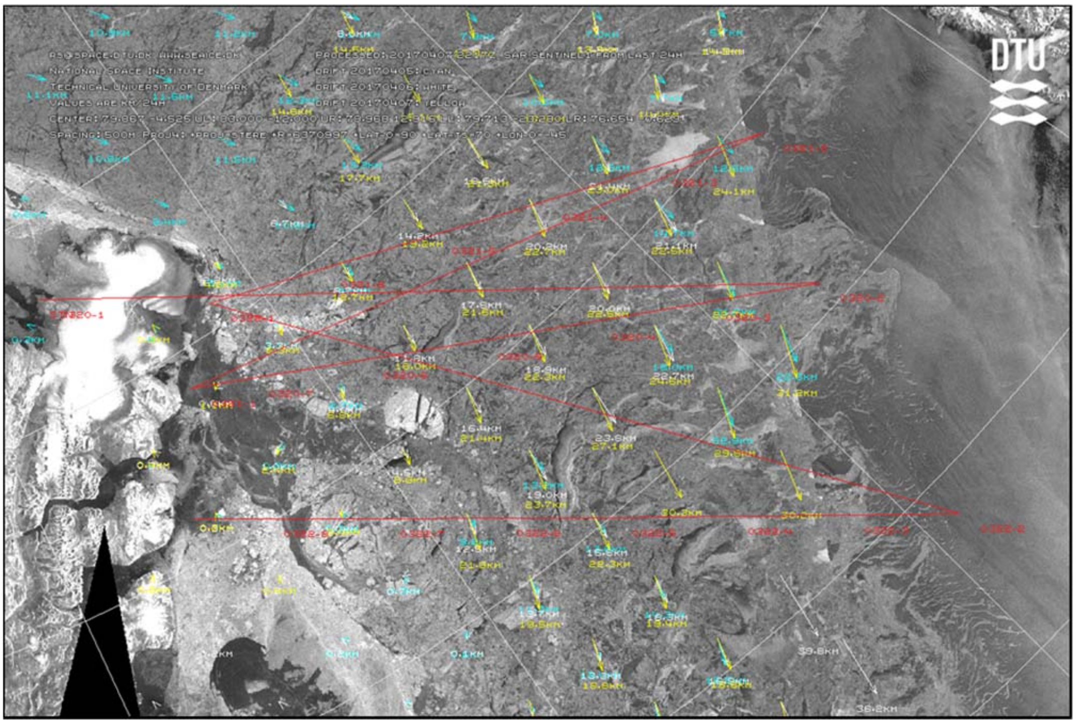

Figure 27: Example of Sentinel-1 SAR image and drift vectors (yellow and cyan) in Fram Strait together with SARAL/AltiKa ground tracks (March 20-22).

6.1.1 Sea ice flights Lincoln Sea

An overview of the flights in the Lincoln Sea using CFS Alert as base is provided in Figure 28, and details of the flights along the NE and NW lines are provided in Table 20 and 21.

As part of the CryoVEx campaign, the Alfred Wegener Institute (AWI) Bassler aircraft (Polar-5) towing an electromagnetic sounder (AEM), was based in CFS Alert for the March 24th flight (NE-line in Figure 28) and NASA's Operation IceBridge P-3 aircraft equipped with multiple sensors for sea ice and snow retrievals was located in Thule AB. Thus, coincident flights along CryoSat-2 ground track #36892 in the Lincoln Sea were coordinated to supplement the CryoVEx airborne sensors (KAREN, ASIRAS and ALS) with a variety of sea ice measurements. As the AWI AEM measures the draft of the sea ice, a comparison to KAREN, ASIRAS and the ALS is very important for the freeboard to thickness conversion. The snow radar (2 to 8 GHz) onboard NASA P-3 is valuable for snow depth estimates to support the potential of measuring snow depth directly with the dual-frequency setup, i.e. KAREN - ASIRAS. As an opportunity a fourth aircraft (DFRC Gulfstream (G-III)) carrying NASA JPL wide-swath topographic mapper (GLISTN) joined the team, and for the first time in CryoVEx campaigns four aircrafts were coordinated along the same flight track.

Coincident flights with AWI Polar-5 and DTU Space Twin Otter are straightforward as the aircrafts fly at the same survey speed of approx. 110 knots at different elevations, e.g. 50m and 300m agl. Thus, the aircrafts are able to align on the same track at the same speed only a few minutes apart, which ensures overlapping data acquisition in areas of drifting sea ice. Such formation flights were performed for the first time during CryoVEx 2011, and have been repeated in 2012, 2014 and now 2017. Due to the higher speeds of the P-3 and G-III, they were on top of the Twin Otter and DC-3 at two interception points, one on the outbound and one on the inbound tracks. Part of the line was surveyed during Phase 2 on April 16, together with observations made by the in situ team at two sites.

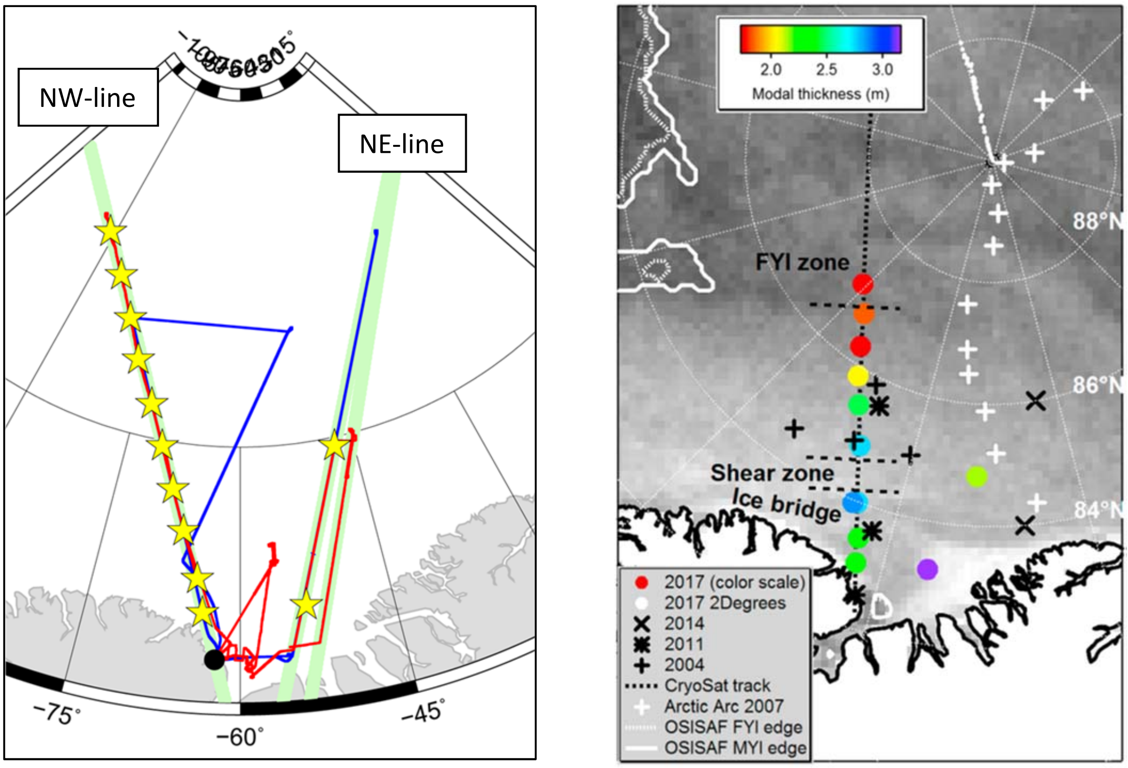

Figure 28: Overview of flights out of CFS Alert (left). Blue flight tracks were flown in phase 1 and red flight tracks in phase 2. Green wide tracks represent relevant CryoSat-2 ground orbits, and yellow stars all the sites visited by the in situ team. Modal thickness from the in situ sites (right) from Haas et al. (2017).

Table 20: Overview of campaign activities following the NW-line in the Lincoln Sea

NW-line

March 27	CryoVEx phase 1 (ALS, ASIRAS, KAREN)
April 11-18	In situ measurements
April 11	NASA Operation IceBridge (ATM, snow depth radar)
April 12	CryoSat-2 orbit # 37159 02:11 UTC
April 13	CryoVEx Phase 2 flight (ALS, KAREN)

Table 21: Overview of campaign activities following the NW-line in the Lincoln Sea

NE-line

March 24	CS2 orbit # 36892 CryoVEx phase 1 (ALS, ASIRAS, KAREN) AWI Polar-5 (EM sounder) NASA OIB (ATM, snow depth radar) NASA JPL GLISTIN (Topographic interferometer (ka))
April 11-18	In situ measurements
April 16	CryoVEx phase 2 (ALS, KAREN)

6.1.2 In situ work Lincoln Sea

To get large scale in situ measurements the ground team landed approximately 30 nm apart along selected CS2 orbits between Ellesmere Island and 87.1°N. The in situ team managed to visit in total 12 sites (10 on the NW line CS-2 orbit #37159 and 2 on the NE line CS2 orbit #36892) marked by stars in Figure 28 between April 11-18.

Unfortunately the BAS Twin Otter was delayed out of Cambridge Bay due to weather, and did not arrive in CFS Alert until the evening of April 12, thus missing the opportunity for a coincident flight with OIB and match of CS2 orbit #37159. The NW-line was surveyed by OIB on April 11th and by the BAS Twin Otter with the KAREN radar and ALS on April 13. The blue line was partly surveyed by the Twin Otter (ASIRAS, KAREN and ALS) in phase 1 on March 27. The NE-line following CS2 orbit #36892 was surveyed during phase 1 by 4 aircrafts on March 24th (blue line) and partly re-flown in phase 2 by the BAS Twin Otter on April 16 (red line).

Detailed description of the in situ work, together with summaries of the data gathered (supplementary material Table S1) has been reported in Haas et al. (2018). Below is given a short summary and first results comparing in situ and airborne measurements of snow depth.

As reported in Haas et al. (2018) the in situ team measured the sea ice thickness from ground EM providing the total sea ice thickness (snow depth + sea ice thickness) along 1.7-5.0 km transects. Coincident observations of snow depth using magnaprobe were measured along the same transects, however, the length of these were usually shorter (0.1-2.5 km) due to the slower progress and limited time on ground (1-2hrs) at each in situ site. Snow pits were also obtained at each site, but are not reported here.

The in situ measurements of modal sea ice thickness are shown in Figure 28 (right). The thickest and roughest ice types are found in the south with mean varying between 2.5-3.8 and the thinnest ice types of mean <2 m in the north. The shear zone is the transition zone between the stationary ice (ice bridge) to the south and the drifting sea ice to the north. The in situ measurements of snow depth show no trend, but some variability between measurements with mean ranging between 30-47 cm (see next Section and Figure 29).

6.1.3 First results of dual-frequency snow depth from KAREN and ASIRAS

First results of inter-comparison of airborne and in situ measurements of snow depth were presented at Polar2018 DAVOS, AGU fall meeting 2018 Washington DC and most recent at ESA LPS19 in Milan. Mean (●) and mode (▲) of the in situ snow depth along the transect at each in situ site are provided in Haas et al. (2017), and plotted in Figure 29, where error bars represent the standard deviation of measurements along each transect.

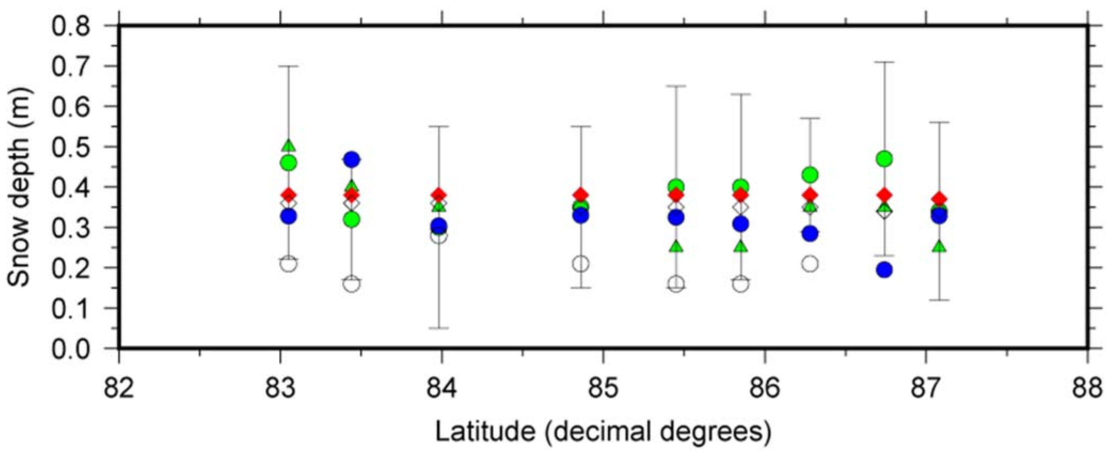

Figure 29: Overview of flights out of CFS Alert (left). Blue flight tracks were flown in phase 1 and red flight tracks in phase 2. Green

Airborne data has been averaged along a 10 km section centered at the location of the in situ site provided in Haas et al. (2017). The mean snow depth obtained by OIB snow radar on April 11 (● Figure 29) tends to underestimate the snow depth when compared to the in situ observations at these scales (10km). However, the OIB data is obtained from the quicklook product, which tends to underestimate the snow depth when compared to the final product, which at the time of writing is not yet available.

In case of a perfect scenario elevation differences of KAREN-ASIRAS should potentially provide information about the snow depth. To see whether this is the case, airborne ASIRAS and KAREN data from flight March 27 (phase 1) has been retracked using a simple 50% threshold first-maximum retracker algorithm (TFMRA) first described by Helm et al. (2014) with suppression of noise on the leading edge of the waveform. Plotted elevation differences (○) in Figure 29 between KAREN and

ASIRAS result in about half of the mean snow depth obtained by the in situ observations. The elevation differences between KAREN and ASIRAS were obtained on March 27 during phase 1, which is 15 to 22 days before the in situ and OIB measurements of snow depth, thus new snow fall and/or redistribution of snow in an occurrence of a storm between measurements will affect the results. Unfortunately it is not possible for to use the flight in phase 2, which was much better timed with the in situ measurements (-2 to 5 days), for dual-frequency snow depth measurements, as ASIRAS was not carried along during phase 2 due to logistic challenges between campaign phases. However, the combined KAREN and ALS for both phase 1 and 2 can be used to test penetration and optimization of re-trackers, as ALS both provides reference for the snow surface and also provide estimate of roughness for the scales provided here.

For comparison the most used Arctic wide snow depth climatology provided by Warren et al. (1999) has been plotted in Figure 29 from March (◇) and April (◆). These, show good agreement with the in situ data for this location and year, as also concluded in Haas et al. (2017). The variation of snow depth from Warren et al. (1999) between March and April is only few cm and not half of the snow depth as found by the dual-frequency elevations. However, one should bear in mind that there can be local and inter-annual variations from the snow depth climatology provided by Warren et al. (1999), see also Section 6.1.6.

Thus, there is still much more to learn using these combined data sets. First of all the reduced propagation speed of light through the snow cover on sea ice floes needs to be applied to the ASIRAS retracked elevations. To a first approximation the corrected freeboard is given by $f_c = f_i + 0.25 * h_{snow}$, the correction is 9 cm which would reduce the dual-frequency snow depth even further. In addition, optimization of retrackers for KAREN and ASIRAS is crucial to learn more about penetration depths, and retrackers dependencies on roughness.

6.1.4 SARAL/AltiKa underflights

During the CryoVEx campaign SARAL/AltiKa was underflown for the first time over sea ice. Due to the lower orbit turn-around latitudes (81.5°N) compared to CryoSat-2 (88.0°N) the flights were located in Baffin Bay on March 31 (Figure 30) and Cambridge Bay on April 5 (Figure 31) following SARAL/AltiKa ground orbit #709 and #846, respectively. A planned underflight of SARAL/AltiKa ground track orbit #387 on March 20 in Fram Strait (Figure 1) was not possible to underfly real time due to time constraints. Due to the large drift rates in Fram Strait 13-18 km/day (see Figure 27) it is not favorable to follow the satellite ground track more than 12 hours after the satellite passage time, which was the case. Thus, an alternative track was selected to overfly a large ice floe south of the satellite ground track, identified in the SAR-images provided to the field team prior to flight. This was large ice floe should be easy to be identified in both the airborne and satellite observations during the post-processing.

All the SARAL/AltiKa flight tracks were from cycle 107. A successful alignment of airborne flight tracks and satellite ground track were not possible without collaboration with CNES providing orbit information directly to the field team few days prior to the flight, as SARAL/AltiKa has been in a drifting orbit since July 4, 2016.

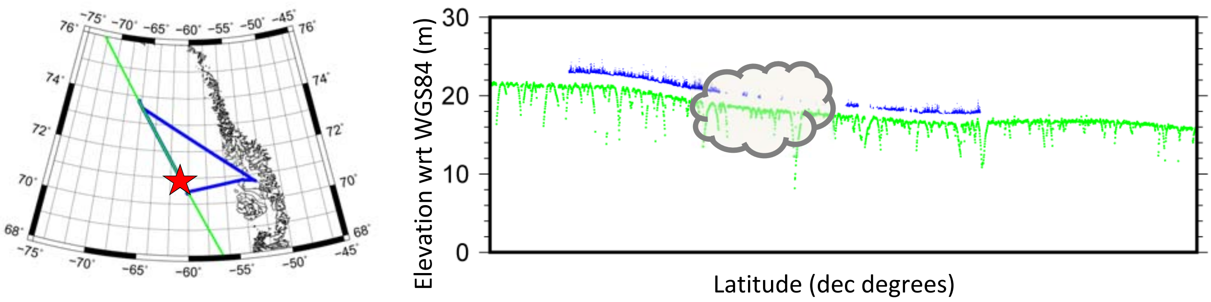

Figure 30: Flight tracks (left) and along-track elevations (right) of first direct underflight of SARAL/AltiKa on March 31. ALS is marked with blue and SARAL/AltiKa with green. The elevations of SARAL/AltiKa have not been corrected for any geophysical corrections, explaining the about 1m difference between SARAL/AltiKa and ALS elevations. Passage time of SARAL/AltiKa during underflight is marked with red star.

Cambridge Bay SnowExp

The CamBay SnowExp 2017 took place in the vicinity of Cambridge Bay, Canadian Arctic, in the period March 31 – April 8. Cambridge Bay provides easy access to the fast ice and the in situ measurements give information of snow penetration both over sea ice and land. The flight on April 5, 2017, was carried out coincident to SARAL/AltiKa satellite pass, and followed up on the overpass with a ground campaign and an under-flight on the same day.

The sea ice in Dease Strait outside Cambridge Bay consists primarily of stationary fast-ice. The airborne and satellite measurements do not provide measurements of sea ice thickness over fast ice due to the lack of open water leads acting as reference for the local sea surface height, but has the advantages of zero net sea ice drift. The combined airborne (KAREN and ALS), satellite (SARAL/AltiKa) and in situ observations of snow conditions, provide information of Ka-band penetration in different snow conditions.

The flight plan for the underflight consisted of 5 parallel flight lines spanning Dease Strait (~40km each), and a 6th calibration line diagonal across the 5 parallel lines. The parallel flight lines were spaced 200m apart, and thus should all be within SARAL/AltiKa ground track which has been suggested as being 1.4 km wide (across track). The middle line (line 3) was directly coincident to the estimated AltiKa ground track. Given the importance of line 3 it was flown twice. The flight lines (red lines) and SARAL/AltiKa ground track (green dots) can be seen in Figure 31. The northern extent of the under-flight lines contained land, to coincide with terrestrial snow sampling activities, whereas the southern extent contained sea ice to coincide with snow sampling activities over sea ice. The respective land and sea ice in situ sites along SARAL/AltiKa are marked with stars in Figure 31.

To investigate the penetration of the airborne Ka-band, radar reflectors (aluminium plates) were placed on the top of the snow pack. The sea ice team laid out four radar reflector lines perpendicular to the AltiKa ground track (flight line 3), and each radar reflector line was separated by 100m. Analysis of the snow thickness data (over sea ice) obtained by this team revealed that the horizontal length scale associated with the snow depth was about 75 m, and therefore by placing the radar reflectors 100 m apart we ensured that each site was statistically different. Each line was 40m in length (across track), with reflectors spaced approximately 4m apart along each line. Bin liners were used as markers for the airborne team and placed at each end of the lines. A similar setup, but with only 3 reflector lines, were laid out at the land in situ site. Given the potential difference in snow conductivity between sea ice snow and land snow this should give some interesting results.

The sea ice ground team laid out a ground survey line parallel to flight line 3 but off-set in the across-track direction by 20m. The 20 m offset was to minimize contamination of the snow seem by the airborne Ka band radar as it flew down line 3. The area sampled was smooth first-year sea ice characteristic of the area and very likely the entire extent of Dease Strait covered by AltiKa and the aircraft. It was situated about 4km off shore in Dease Strait, accessible by snowmobile from Cambridge Bay. Snow pits were conducted every 100m along the ground survey line. Snow temperature, density, conductivity, was measured at 2 cm intervals. Snow structure, hardness, and grain size was recorded by layer. Ice thickness and freeboard adjacent to the snow pit was measured twice. In addition, a 20 by 20m snow thickness grid was set-up around each snow pit. Snow thickness and GPS coordinate was measured at 1m spacing in the grid using a snow magnaprobe. A total of 5 snow pits and 20 by 20 snow depth grids were obtained on the survey day April 5. The terrestrial team preformed a similar snow survey.

The site was revisited the following days. On April 6 a snow depth transect 1.5 km long with 1m spacing was done along the in situ line, beginning at the first radar reflector line and extending appx. northward towards shore. Two more snow pits, ice thickness measurements, and 20 by 20 snow depth grids (this time 5m spacing) were done. On April 7 the two deep snow pits were excavated since the team felt that, after looking at the snow depth distribution data, the deeper snow cover hadn't been properly sampled. Two, 2km long, snow thickness transects with 100m sampling intervals were taken along the AltiKa line, beginning at the first radar reflector line and extending approx. 2.75km northward to the shore. The two lines were spaced 100m apart in the a-long track direction.

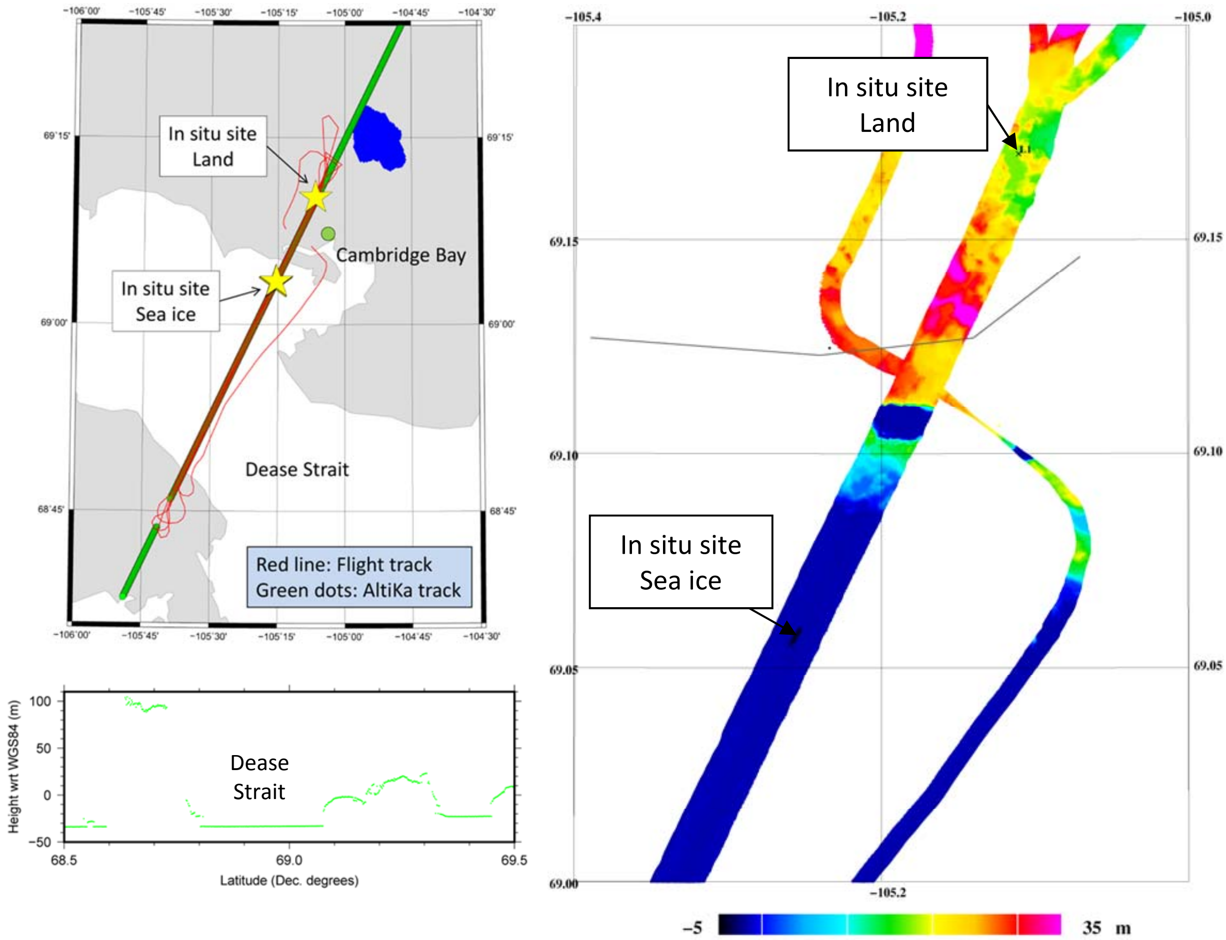

Figure 31: Overview of sea ice flight April 5 out of CFS Alert (top left), elevations of SARAL/AltiKa (bottom left), and final processed ALS elevations (right).

6.1.5 Sentinel-3A under flights

First underflights of Sentinel-3A were performed during ESA CryoVEx 2016 spring campaign in the Fram Strait. Preliminary results were presented by Skourup et al. (2017). This was followed by two direct underflights during CryoVEx 2017 one on March 29, 2017, in Nares Strait and Hells gate on the route to Devon ice cap and one additional flight on April 24, 2017, in Fram Strait on April 24, 2017. An overview of Sentinel-3A underflights of both CryoVEx 2017 and CryoVEx 2016 spring campaign is provided in Figure 32.

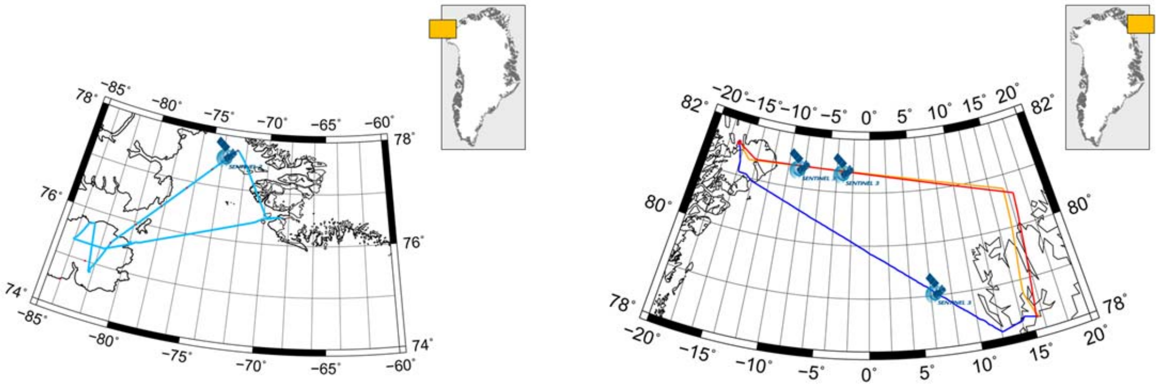

Figure 32: Sentinel-3A flights in Nares Strait (left) and Fram Strait (right). Flight track March 29 2017 (Light blue), April 24 2017 (dark blue), April 6 2016 (red) and April 10 2016 (orange). Sentinel-3 satellites mark passage points of the satellite during the flight.

6.1.6 Overflight of NPI Fram Strait ULS moorings

Norwegian Polar Institute (NPI) maintains an array of upward looking sonar moorings located at about 78°50'N latitude in the Fram Strait measuring the sea ice draft continuously in time (Figure 33). The buoy located western most in the array (F14) at 6.50°W was overflown on March 20, 2017, along a straight N/S line to account for sea ice drift. Similar overflights have been collected multiple times since 2005 see overview Figure 33 and Table 22. The buoys F11 (2005) and F13 (2014) are located east of F14 at 3.25°W and 5.00°W, respectively.

Unfortunately there are only 4 sufficient data sets (2005 F11, 2014, 2015 and 2016) from the mooring sites overlapping with the airborne campaign data. Buoy data from 2017 was not available at the time the data was requested (March 2018), as the buoy needs to be physically removed and downloaded. The lacking data (2005 F14, 2008, 2011 and 2012) is either due to instrument failure or in 2011 due to loss of the whole mooring (Laura De Steur (NPI), personal communication, March 2018). Loss of data could have been reduced or completely avoided by overflying more than one buoy, but has always been a trade-off due to limited flight hours and other obligations during the dedicated flights. The priorities should be re-considered for future campaigns to increase the success rate of coincident ULS and airborne data sets.

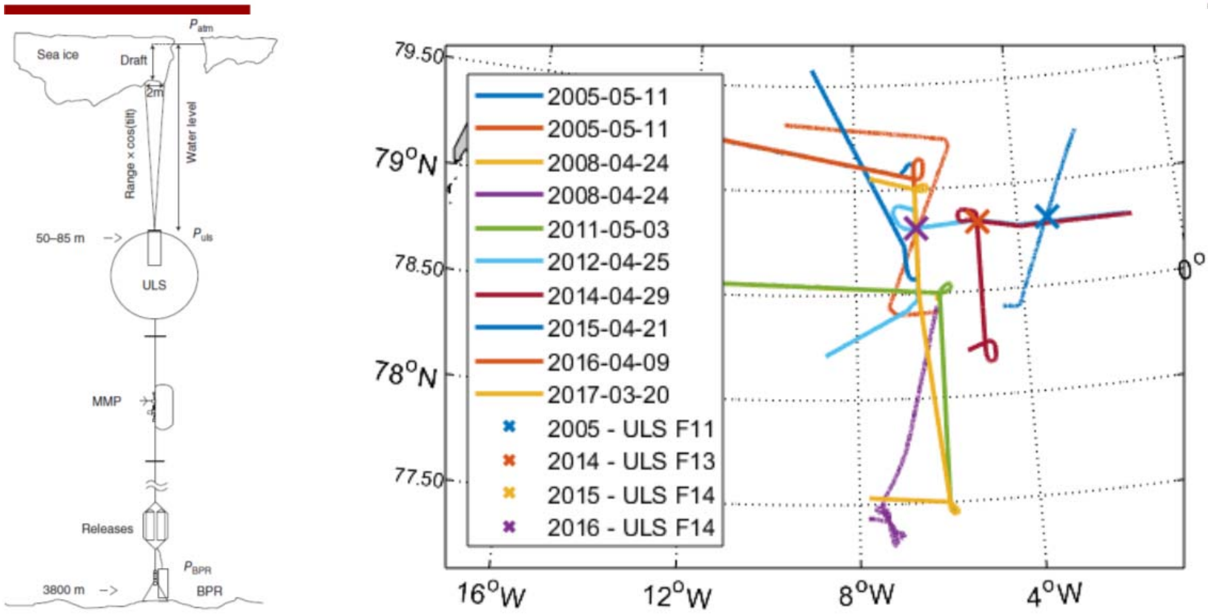

Figure 33: Schematics of a moored ULS buoy (right). Flight tracks and NPI ULS buoy locations in Fram Strait (left).

Mean and mode sea ice freeboards from ALS (short N/S-directed subsection) and mean draft from ULS (time of overflight ±24 hours) was compared in a small study by Borby-Nielsen (2018) and is presented in Table 22. The ULS data was kindly prepared by Laura De Steur and Olga Pavlova (NPI). ALS data has been drift corrected using OSI-SAF low resolution sea ice drift product, using the drift vector located nearest to the ULS position. Direct comparison using drift corrected ALS data only within 5 m of ULS draft data show high correlation.

As it turned out the drift was very rarely drifting directly N/S as presumed, and in future campaigns it is recommended to get the local drift direction prior to the flight and use it to define the desired flight direction.

Conventional methods to estimate sea ice thicknesses from altimetry derived sea ice freeboards are based on the assumption of isostatic equilibrium. This conversion requires knowledge of snow depth together with knowledge of densities of sea ice, snow and ocean water. The largest uncertainties are by far caused by the large uncertainties in the current snow depths used as input (e.g. Ricker et al. (2014) or Giles (2007)). Arctic wide snow depths to support sea ice thickness estimates from satellite altimetry is typically based on Warren climatology (Warren (1999)). This climatology is based on in situ measurements obtained in the central Arctic in the period 1954-1991. Where Warren has no direct observations in Fram Strait and extrapolates measurements obtained in the central Arctic a more recent study by Forsström et al. (2011) makes a similar local snow depth estimates based on observations obtained in the Fram Strait in the period 1999-2008. However, neither of them provides information of inter-annual variations.

Coincident measurements of sea ice freeboard (F) and draft (D), as obtained by airborne altimetry and ULS moorings could directly provide a conversion factor (k) to be used for freeboard to thickness (T) conversion without prior knowledge of snow depth.

$$T = k * F \quad \leftrightarrow k = \frac{T}{F} = \frac{(F + D)}{F}$$

Results of the k-factor are provided in Table 22. As seen the values changes slightly between successive years and reflects inter-annual variations in snow depth, ice type and/or deformation of the sea ice. The values listed are comparable to the values of level ice (k=4.4) and deformed ice (k=5.2) found in a local study in the Beaufort Gyre by Doble et al. (200**8**) using coincident measurements of ALS and upward looking sonar from an AUV.

These combined data sets are unique and can be used to validate the sea ice freeboard to thickness conversion in a very dynamic sea ice area. Here we have used only ALS data, which would represent ICESat-1 and ICESat-2, whereas a similar study using ASIRAS would resemble CryoSat-2 and Sentinel-3.

Table 22: List of combined ALS and ULS

Date	ULS mooring		Freeboard mean (m)	Freeboard Mode (m)	Draft mean (m)	k-factor (unit-less)
			ALS	ALS	ULS	
2005-05-11	F11	EU GreenICE	0.65	0.73	X	N/A (no OSI-SAF)
2005-05-11	F14	EU GreenICE			N/A	N/A
2008-04-24	F14	ESA	0.50	0.23 and 0.47	N/A	N/A
2011-05-03	F14	ESA	0.67	0.68	N/A	N/A
2012-04-25	F14	ESA	0.62	0.55	N/A	N/A
2014-04-29	F13	ESA CryoVEx	0.55	0.15	2.38	5.32
2015-04-21	F14	EU ICE-ARC	0.66	0.63	2.05	4.10
2016-04-09	F14	EU ICE-ARC	0.59	0.54	2.23	4.78
2017-03-20	F14	ESA CryoVEx	0.47	0.24	N/A	N/A

6.1.7 Supporting sea ice flights

CryoSat-2 airborne array

As part of the ESA CryoVal Sea Ice project, it was concluded that direct comparison of CryoSat-2 and airborne data averaged to the CryoSat-2 SAR footprint size (~300m x 1,600m) did not have any or very low correlation, most likely due to the limited across-track coverage of the airborne data. Thus, direct comparison is not possible. However, as shown by Haas et al. (2016) the correlation improved by averaging both data sets along 50 km sections.

As a proof of concept a swath approach similar to CryoVEx 2016 spring campaign over Austfonna ice cap was flown over sea ice along CS-2 orbit #37225 on April 16. Five parallel lines along 50 km sections were flown to map 167 along-track CS-2 footprints covering the full width of the CS2 across-track footprint size to test whether it is possible to better resemble the area average of each CryoSat-

2 footprint, e.g. represented by single waveforms (see Figure 34). The area was correlated in space and time with CS-2 passage (Table 19) in an area with open leads.

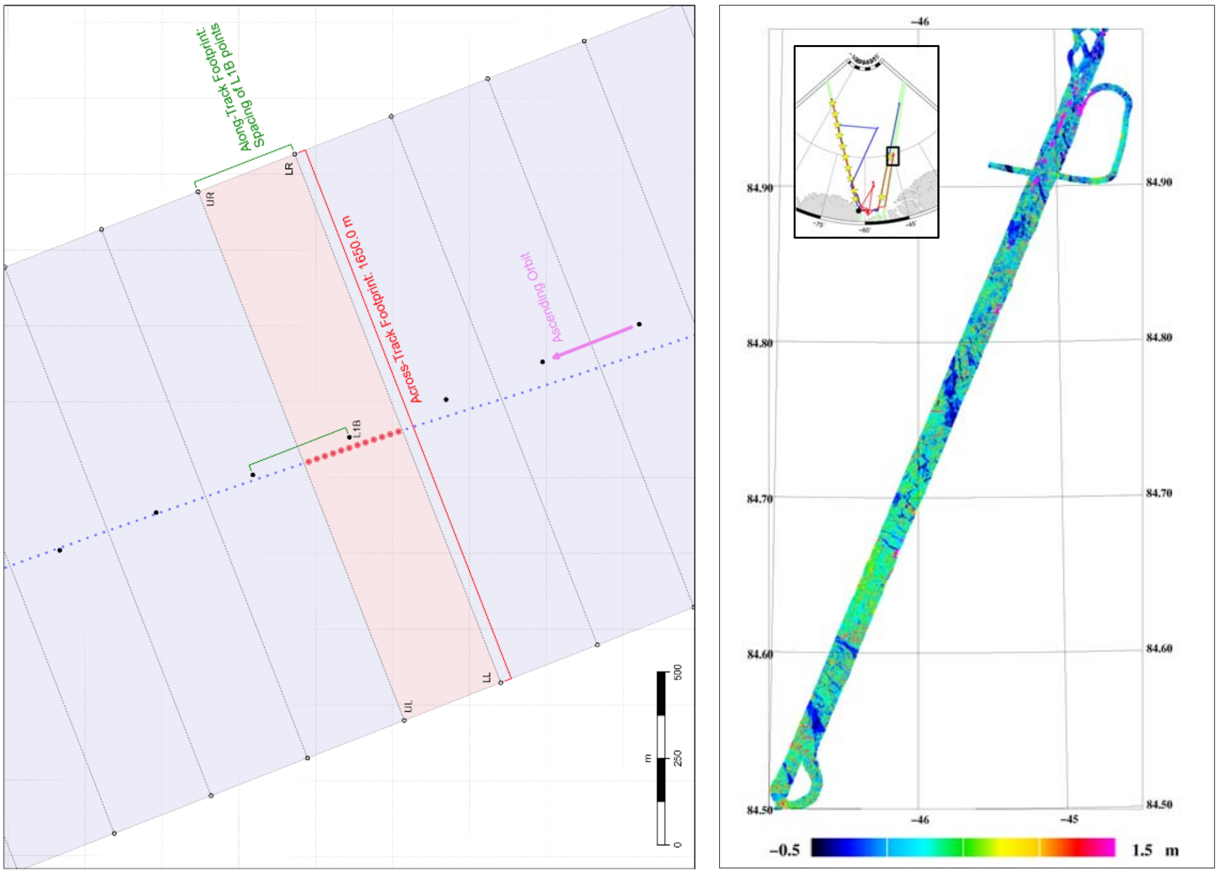

Figure 34: Illustration of resampling of airborne data onto CryoSat footprints (left) Figure 4 in Baker et al. (2016). All airborne data (red dots) within a CryoSat footprint (red rectangle) are averaged and projected onto the CryoSat nadir location in the center of the footprint shown by a black dot. ALS elevations w.r.t. WGS84 of full swath of parallel lines from flight on April 16.

Shearzone and icebridge

The flight on April 18 included crossing of the transition zone between the stationary ice and the drifting sea ice also known as the shear zone (Figure 35). This was combined with overflight of the polynya formed next to the ice bridge in the north-eastern part of the Nares Strait outside CFS Alert (Figure 35). The polynya was partly covered by open water with low fog and areas with new ice. The measurements were assisted by airborne radiometer and infrared thermometer, which has the potential to provide new information of polynyas. The ice bridge finally collapsed mid-May .

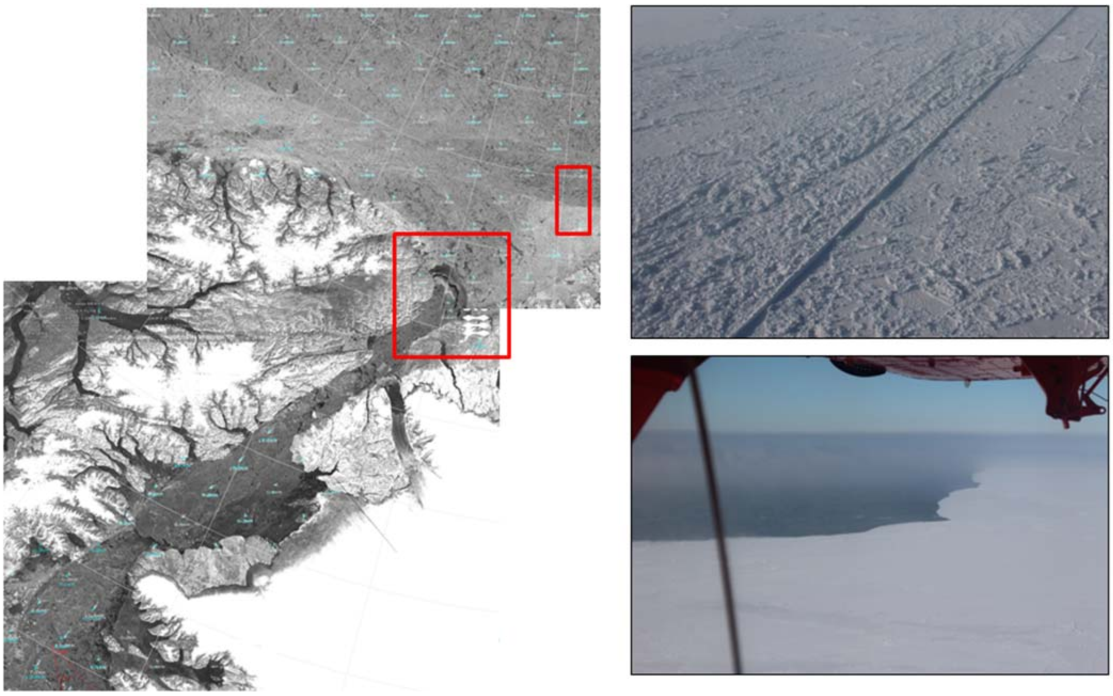

Figure 35: SAR image from the Nares Strait area (left) with photos of shear zone (top right) and polynya next to the icebridge (bottom right).

Triangle flight and transit flights

The triangle flight flown out of Station Nord (Figure 1) on March 21, has been monitored routinely since 1998, and comprises a unique time-series in an area feeding into the largest sea ice freshwater outflow of the Arctic, the Fram Strait, see also Skourup et al. (2018b). Whenever possible transit flights were used to acquire additional data, e.g. the Canadian channels where the distribution of sea ice types is of interest.

L-band SAR

The Japanese Aerospace Exploration Agency (JAXA) kindly acquired L-band SAR images in the areas surveyed, which provide different information in e.g. sea ice classification as compared to, commonly used C-band SAR from Sentinel-1A/B, see e.g. Singha et al. (2018).

6.2 Land ice

The primary flights during CryoVEx/ICE-ARC 2017 airborne campaign were the flights over the EGIG line with coincident in situ measurements. An overview and first comparisons of the airborne and in situ observations are provided in Section 6.2.1. Over the land ice no direct underflights along satellite ground tracks are provided, however, crossings of the ice sheet e.g. the EGIG-line and north Greenland, provides cross-overs of all altimeter missions including CryoSat-2, Sentinel-3 and SARAL/AltiKa. Dedicated flights at Austfonna and Devon, are described in Section 6.2.2 and 6.2.3, respectively.

6.2.1 EGIG line

The CryoVEx 2017 airborne campaign was aimed at the EGIG-line to document the different glacial facies along this well studied line of way-points. Six sites (T5, T9, T12, T19, T30 and T41) were visited by the in situ team see Figure 36 and Table 23 during the field campaign supported by ski-equipped Twin Otter from Norlandair.

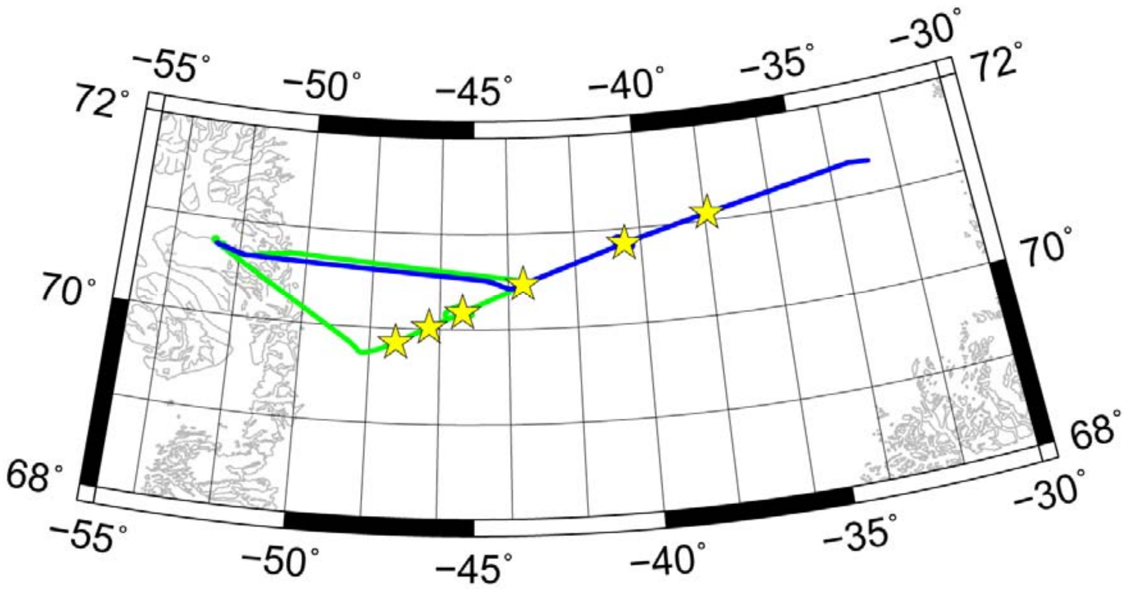

Figure 36: Overflight of the ground team. The metal plates placed on the ground above the tail of the helicopter is acting as surface indicators in the radar return signal.

The information listed below provides a general schedule for the land ice field campaign:

Wednesday, March 29	ADB and SSIM CPH to AEY
Thursday, March 30	Flight AEY-CNP-T41-T5-JAV Visit the sites T41, where snow core was drilled along with density measurements in pit. At T5 only a snow core was drilled.
Friday, March 31	Flight JAV-T19-T12-T9-JAV
Saturday, April 1	Flight JAV-T30-JAV
Sunday, April 2	ADB and SSIM return to CPH.

Five in situ measurements were collected during the land ice campaign. This consisted of GPS measurements of the site location, a shallow firn core, a snow pit of the top 30cm of snow that could not be cored, pRES radar measurements, and metal reflectors for the airborne overflight.

Table 23: Overview of CryoVEx 2017 EGIG site locations.

Site	Base station start (UTC)	Base Station stop (UTC)	Processing	Latitude [deg. N]	Longitude [deg. W]	Altitude above ellipsoid [m]	Orthometric elevation[1] [m]
T5	18:18	19:05	Maxtor	69 51.13787	47 15.32759	1937.09	1902.20
T9	17:13	17:50	Maxtor	70 01.19598	46 18.37317	2145.39	2108.47
T12	15:12	16:00	Maxtor	70 10.56013	45 20.65050	2346.93	2308.32
T19	12:44	??:??	Maxtor	70 28.20306	43 33.80099	2659.24	2618.93
T30	10:39	??:??	Maxtor	70 51.00095	40 30.00328	3014.08	2970.15
T41	14:49	15:59	Maxtor	71 04.72094	37 55.18671	3014.08	3153.61

Due to time constraints at each site, and the necessity of each measurement, not all experiments were conducted at each site. For example, at some sites the ice core could be collected directly from the surface of the snow due to the presence of a wind crust, therefore negating the need for a snow pit. Equally if the airborne team were not scheduled to overfly the site while the ground team was at a site they did not put out the metal surface reflectors. Table 24 below provides an overview of which measurements collected at each site.

Table 24: Overview of acquired data at the T-sites

Date	Site	GPS	Core	Radar	Pit	Overflight reflectors
March 30th	T41	X	X	-	X	-
March 30th	T5	X	X	-	-	-
March 31st	T19	X	X	X	X	X
March 31st	T12	X	X	X	-	-
March 31st	T9	X	X	X	-	-
April 1st	T30	X	X	X	-	X

The pRES in situ radar data was collected using an agilent network analyzer operated from a thermally insulated box, with antennas that can acquire data in the Ku-Band part of the electromagnetic spectrum. The kinematic pRES equipment set up inside the twin otter plane, with the antenna boom pointing out of the side door, mounted 1 m above the snow surface, over fresh snow that was not disturbed by the twin otters ski footprint. 10 static measurements were collected over the same patch of clean snow, and these 10 shots were then averaged to form one mean profile, dampening out any noise in the data. A second set of 10 shots were collected after a metal plate was placed on the snow surface in order to create a highly reflective surface that could be used to calibrate the snow surface. These 10 shots were also averaged into one mean profile.

[1] Geoid16

We extracted measurements acquired by the ASIRAS airborne sensor at each of the three radar sites examined, T9, T12 and T19. In addition to the measurement acquired closest to the ground campaign sites, we took five measurements from either side of this point to create a mean profile for the field site. Both the airborne and in situ radar profiles were converted to depth using the speed of light (c) and the bandwidth of the sensor (1 GHz for ASIRAS, 15.9GHz for the pRES). The resulting vertical resolution of each sensor is 7.965 cm for ASIRAS and 0.68 cm for the pRES. The following plots (Figures 37, 38, and 39) show the depth vs power profiles for each field site for both the pRES and ASIRAS radars, where higher power returns indicate the presence of an expected layer in the snow pack.

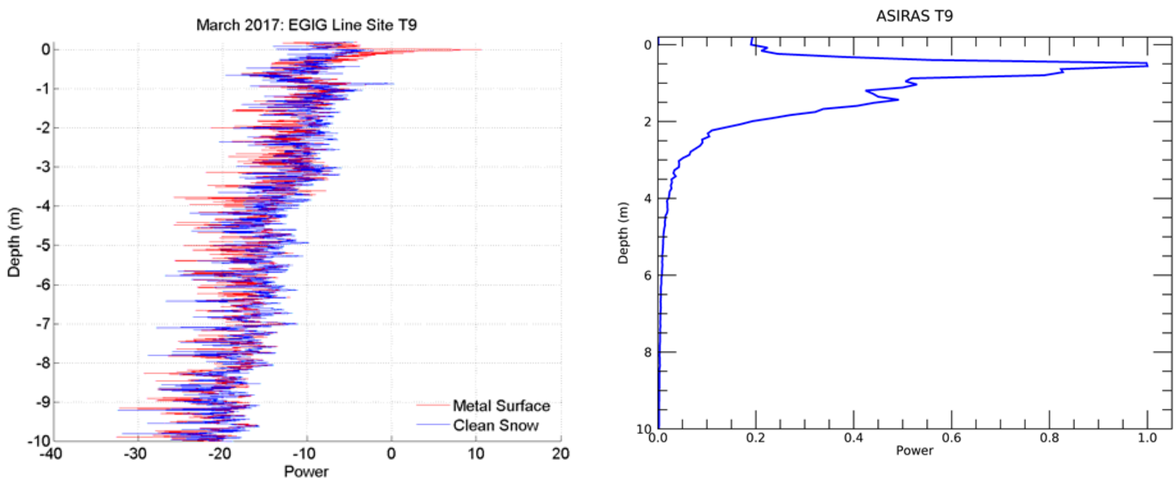

Figure 37: pRES (left) and ASIRAS (right) mean power to depth profiles for site T9 on the EGIG line, Greenland.

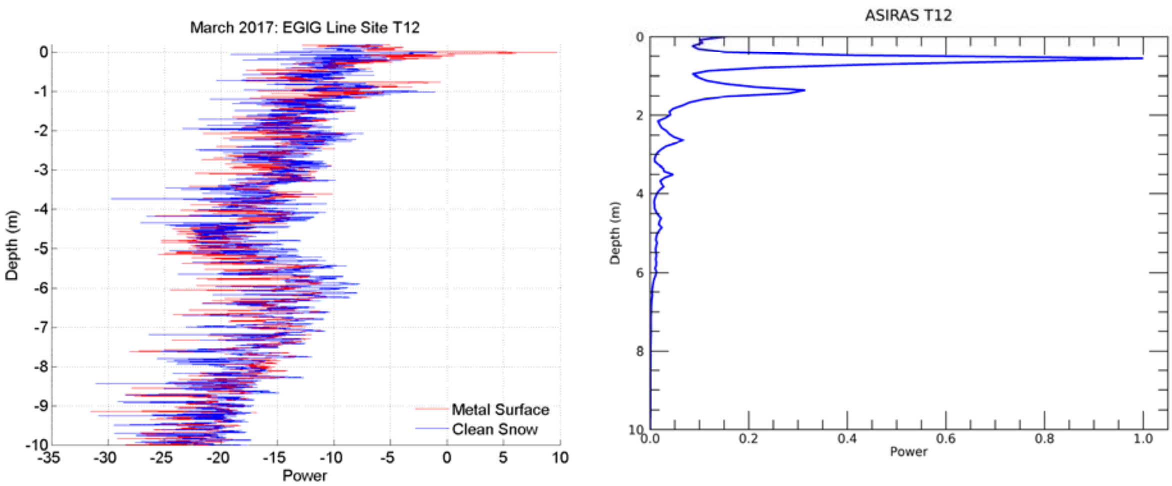

Figure 38: pRES (left) and ASIRAS (right) mean power to depth profiles for site T12 on the EGIG line, Greenland.

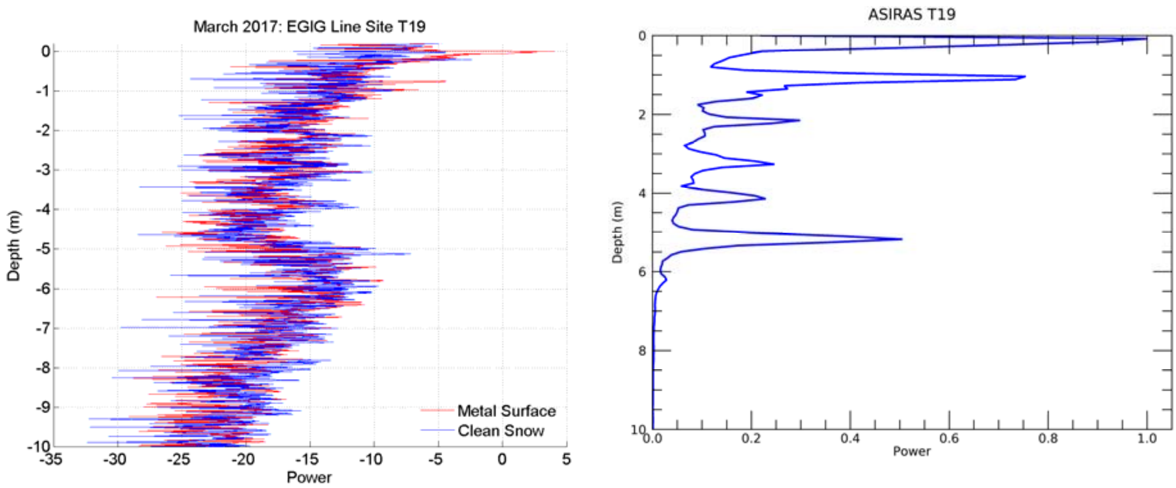

Figure 39: pRES (left) and ASIRAS (right) mean power to depth profiles for site T19 on the EGIG line, Greenland.

Figure 37 shows the pRES and ASIRAS depth to power profile from site T9 on the EGIG line on the Greenland ice sheet. The snow surface is clearly picked out by a high power return in the pRES data when a metal plate is placed on the snow surface (red line). In the profile obtained on clean snow, without a metal plate on the snow surface (blue line) we can see that the highest power return comes from approximately 1 meter below the snow surface, with no obvious peaks (layers) in the snowpack below it. This result is similar to the one we obtained from the mean depth to power profile in ASIRAS data acquired at the same site, where a single broad return is seen in the depth profile, with the peak at approximately 0.5 to 1 meter below the surface. At site T12 (Figure 38), we again see the strongest returns from two layers located within the top 1 to 2 meters of the snow pack. These peaks are present in both ASIRAS and pRES data. In the pRES data from site T12 we also see a broad high power peak approximately 6 meters below the snow surface, however this snow layer is not visible in the ASIRAS data. This may suggest that at site t12 on the EGIG line that ASIRAS data does not penetrate this deep into the snowpack. In the dry snow zone at site T19 on the EGIG line (Figure 39), we see multiple layers in both the ASIRAS and pRES data. There are two very strong peaks seen at the snow surface and then at 1 meter depth in both the ASIRAS and pRES data, followed by three lower power peaks located between 2 and 4 meters depth. An extremely strong power return, almost equivalent in amplitude to the first two surface and sub surface peaks, at approximately 5 meters depth. It is likely that this peak is the same one seen at 6 meters depth in the pRES data from site T12, which may suggest that at site T19 on the EGIG line volume scattering from up to 6 meters depth should be expected. This is in line with theory that suggests more volume scattering should be expected in the dry snow zone.

When we show the ASIRAS data along the whole EGIG line in a depth vs distance plot, with the power of each waveform indicated by the colour scale, we can see how the stratigraphic layers seen in the ASIRAS power to depth profiles vary across the Greenland Ice Sheet (Figure 40 top). The layers are not so clearly visible at low elevation sites at the margin of the Greenland Ice Sheet, as in the ablation zone ice cores show that there is now layering, only solid ice present (Figure 40 bottom). From site T12 onwards, by looking at the waveforms along the EGIG line, layers in the snowpack can be identified as the radar signal penetrates in the snowpack and is backscattered when a change in density is encountered. The strongest return comes from the surface but several weaker reflections below the surface can also be seen in the dry snow zone. The stratigraphy of the snowpack is varying across the profile. Near the margins of the ice sheet, barely any layer can be distinguished whereas further inland, several highly reflective layers can be identified with these different layers corresponding to annual accumulation periods (Hawley et al., 2006; de la Peña et al, 2010). Assuming that the different internal layers each corresponds to an annual accumulation layer, we can clearly identify at T41 the different accumulation layers until 2012. Furthermore, it can be noted that the 2012 layer is highly reflective compared to the following, more recent layers and could correspond to the extreme melt event of 2012.

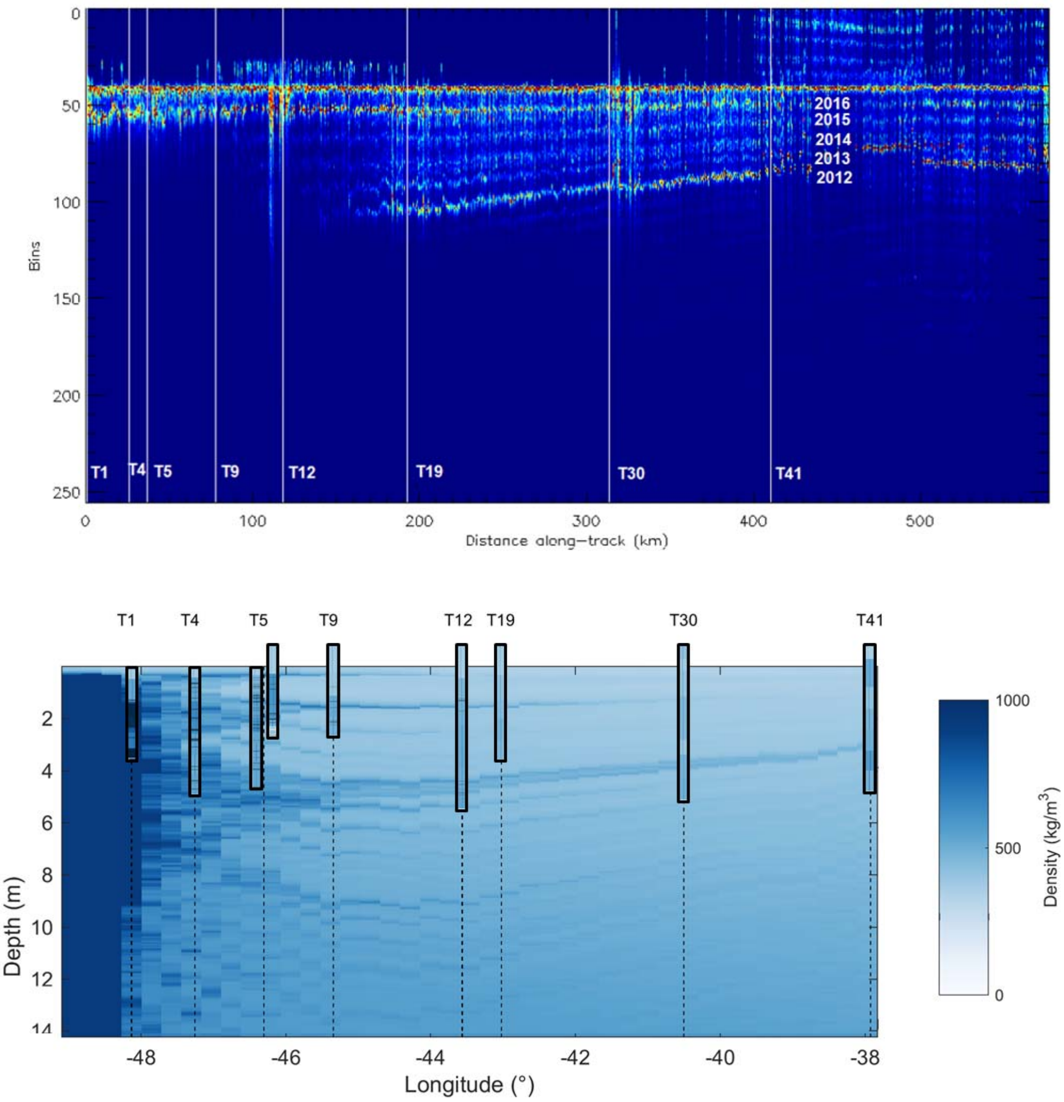

Figure 40: ASIRAS waveforms over the EGIG line (top) and Firn cores collected during the CryoVEx campaign and density profile from the RACMO model (bottom).

We compared a density profile from RACMO (Regional Atmospheric Climate Model) with the 9 firn cores collected during the CryoVEX campaign (Figure 40 bottom). There is a good agreement between the firn cores and the modelled densities. The density decreases along the profile as we move further from the margins where the surface density is almost at the density of ice. At T12, a very dense layer can be seen in the firn core at a depth of 1.5 m and at a similar depth of 1.7 m a dense layer is also found in the modelled density.

To investigate how these snow properties affect the elevations measured by the Ka- and Ku-band sensors, we looked at the difference between Ka and Ku-band airborne data over a section of the EGIG line of 2 km located between T19 and T30 in central Greenland (Figure 41). We retrack the waveforms using a TFMRA (Threshold First-Maximum Retracking Algorithm) using a 50 % threshold and calculate the corresponding calibration offsets to get the absolute heights. Across this section of the EGIG line, the difference between KAREN and ASIRAS data is stable with a mean difference of -0.84 cm and an associated standard deviation of 7.9 cm. In the analysis the offsets as provided in Section 5.6 to get absolute elevations has not been applied to ASIRAS nor to KAREN. In order to compare absolute elevations and related snow properties the ASIRAS elevations need to be corrected with a positive offset of 3.83m and KAREN with a currently unknown offset, as the offset provided in Section 5.6 is based on “levb” processing. Previous processing of “hamh” OCOG re-tracking was -1.60m. Adding these offsets, KAREN and ASIRAS would both be close to the ALS with close to 0cm differences and an associated standard deviation of 0.09 m. Thus both plots in Figure 41 should be adjusted using absolute elevations instead of the elevations used.

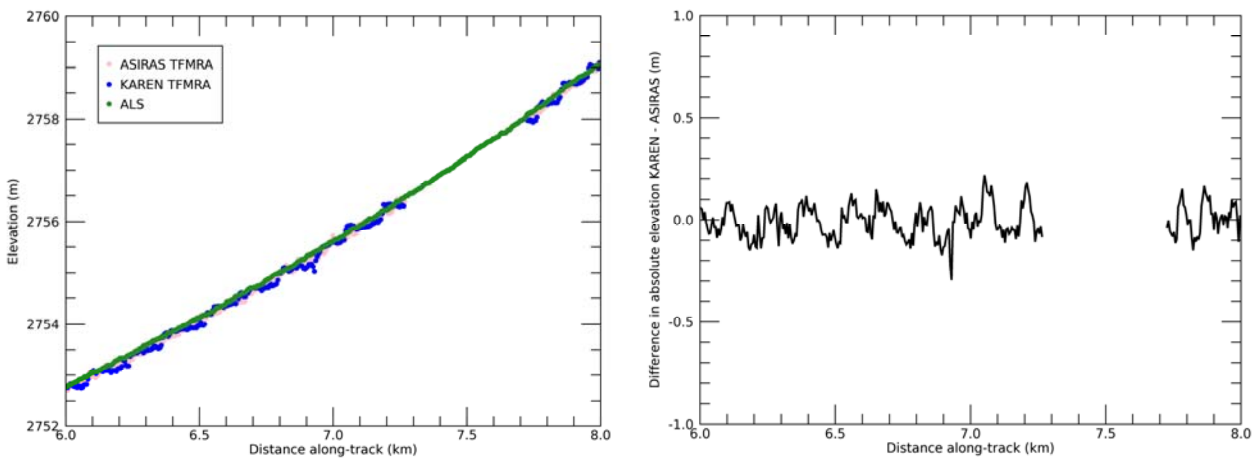

Figure 41: **Re-tracked surface elevations along a section of the EGIG line from Ka (blue line) and Ku-band (pink line) airborne data. Calibration offsets from runway overflights have been applied (3.63 m for ASIRAS and 0.16 m for KAREN). Also shown is the surface elevation measured by the ALS laser altimeter (green line) also onboard the same flight. Right shows the elevation difference between the Ka and Ku-band sensors. The gap in the data is due to roll angles exceeding ± 1.5°.**

6.2.2 Austfonna

The Austfonna ice cap (Figure 42) was flown on April 25-26. A similar approach was used as in Sørensen et al. (2018) based on flights from the CryoVEx 2016 spring campaign to form a dense grid of parallel lines centered around CryoSat-2 orbit #31971 from April 19, 2016. Spacing between parallel lines was 2 km apart. Unfortunately the south-eastern part of the survey area was covered in low clouds and resulted in a shortening of the flight lines. On the inbound flight on April 25 the flight surveyed the ice divide, following plans of the in situ team (NPI/University of Oslo) working on the ice cap.

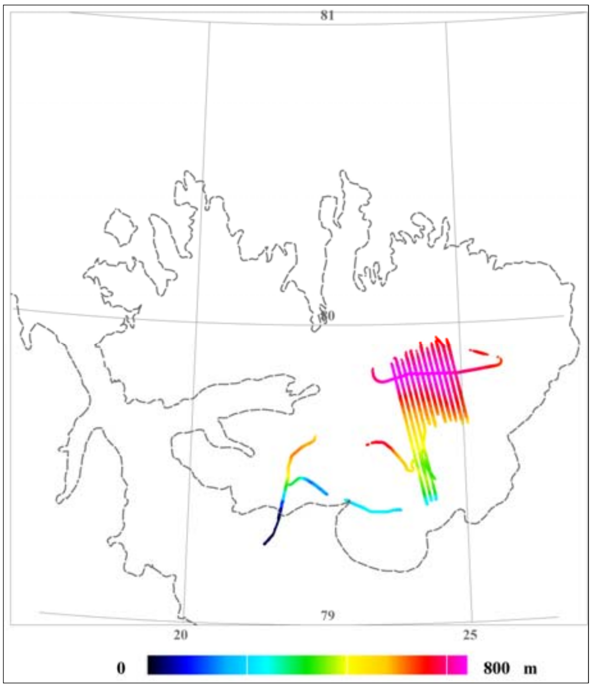


Figure 41: Overflight of Austfonna ice cap April 25 and 26.

6.2.3 Devon

Devon ice cap was overflown on March 29, repeating flight lines of previous CryoVEx campaigns. The flight was not coordinated with in situ work, but the flight lines were crossing corner reflectors left from 2016. These could potential act to check the time tagging of the radar data, but this was difficult to see the reflections from the corner reflectors in the waveform data, as these were covered with snow, see also Section 5.7.

6.3 Land

To support validation of a new high-resolution NASA digital elevation model (DEM), a very tight flight pattern of parallel lines were flown over land in Cambridge Bay on April 7 and 8 (Figure 43, upper plot). Statistics at ALS cross-over points are within the expected accuracy with biases less than 6 cm and standard deviation less than 9 cm (Table 11).

During the survey, GPS ground control points were collected on April 7 by the ground team along a flight track marked by yellow stars in Figure 43 (upper plot) and point A-F in Figure 43 (lower plot). Here point A and F are located at the same spot. The GPS control points have been geo-located accurately with static post-processing of the observations using NovaTel Waypoint 8.20 GrafNet software. The related statistics are found in Table 25 (column 1-8) and show sub 3 cm accuracy, except at point A due to unknown reasons.

A comparison of the ALS data and the ground control points show consistency within 10 cm (Table 25) both using nearest ALS point (column 9) and an average of the 9 nearest points (column 10). Note that point A/C show an offset of 18/19 (17/18) cm when compared to nearest neighbor (9 nearest neighbors) of ALS. As point A has the poorest solution this is expected. The increased difference in point C is currently unknown.

Table 25: GPS ground control points acquired in Cambridge Bay on April 7 and differences between statistic GPS ground control points using nearest ALS point (column 9) and an average of the 9 nearest ALS points (column 10).

Station ID	Latitude	Longitude	Height (WGS84)	Solution Type	std	rms	GPS Base-line	ALS-GPS	ALS-GPS 9
	Deg	Deg	m		mm	mm	km	m	M
A	69.1537187831	-104.898407602	-16.335	Bad	7.2	29.0	6.9	-0.18	-0.17
B	69.1524464008	-104.884377758	-13.971	Good	2.6	12.5	7.3	-0.06	-0.01
C	69.1515809089	-104.873061736	-10.813	Good	2.7	17.3	7.7	-0.19	-0.18
D	69.1505728308	-104.861349459	-10.886	Good	2.4	12.5	8.0	0.05	0.03
E	69.1497204036	-104.851798620	-4.463	Good	2.4	15.2	8.3	0.02	0.05
F	69.1537180464	-104.898412341	-16.114	Good	2.1	15.2	6.9	0.05	0.08
REF	69.1217085444	-105.046288608	-20.070	Unprocessed					

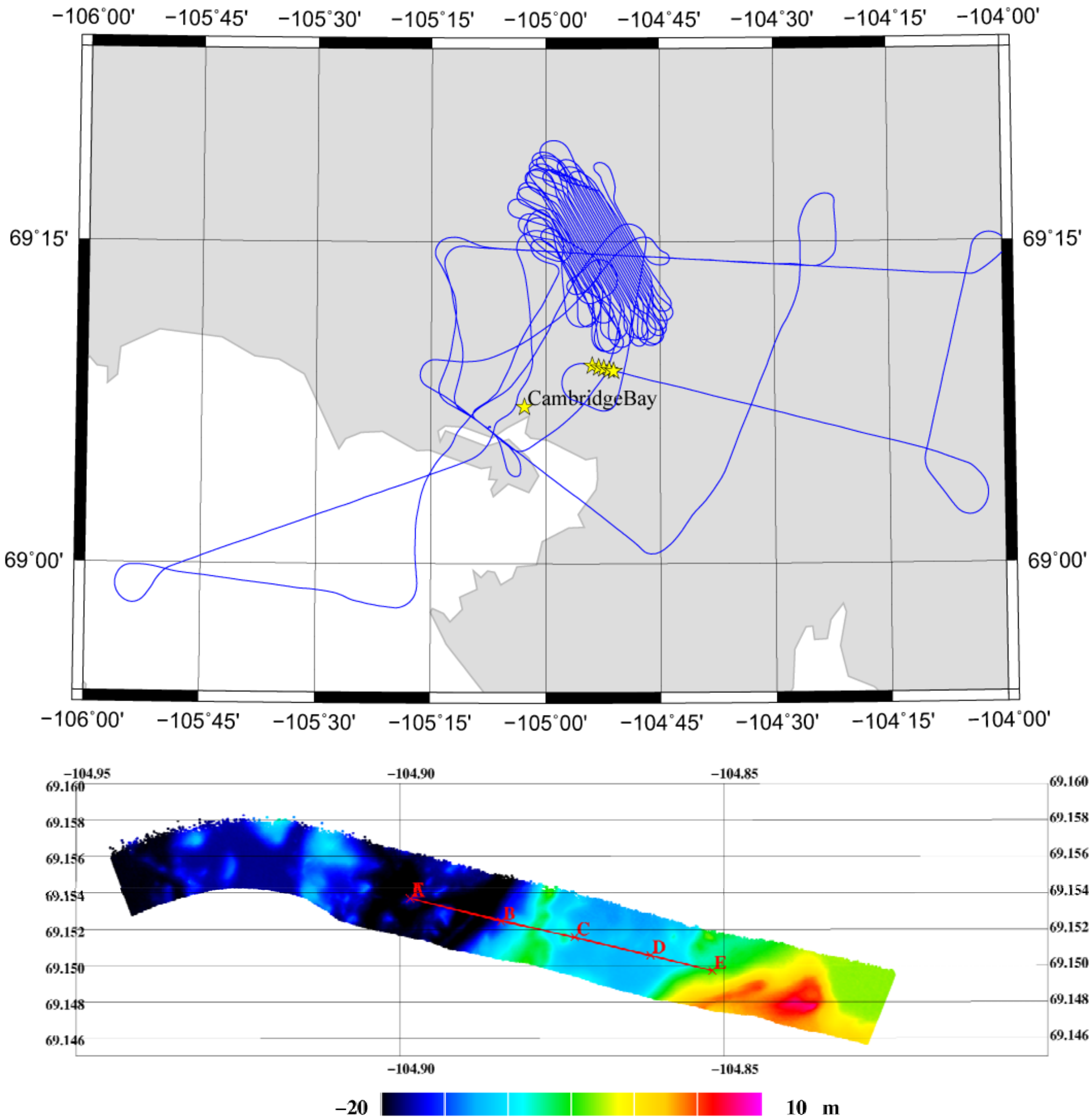

Figure 42: Flight tracks over catchment basin in Cambridge Bay April 7-8. Yellow stars (upper plot) represents collected GPS ground control points. Sub-plot of ALS elevations w.r.t. WGS84 along the GPS ground control points A-E (lower plot).

7 Conclusion

The CryoVEx/KAREN 2017 campaign has collected a unique data set along a total of five CryoSat-2, two Sentinel-3 and two dedicated SARAL/AltiKa ground tracks over sea ice in different location representing different sea ice types and settings. The flights were coordinated with extensive large scale in situ work both over sea ice north of CFS Alert and along the EGIG line on the Greenland Ice Sheet. Crossings of the Greenland ice sheet includes multiple crossovers of all altimeter missions including CryoSat-2, Sentinel-3A and SARAL/AltiKa. For the first time four aircrafts with a variety of instruments were coordinated to measure along a CryoSat-2 ground track over the sea ice out of CFS Alert. This also included the first successful dedicated underflight of SARAL/AltiKa coordinated with Cambridge Bay in situ snow experiment (CamBay SnowExp), despite challenges due to the satellite being in a drifting orbit.

First part of the campaign included dual-frequency airborne measurements using ESA's Ku-band radar (ASIRAS) and MetaSensing Ka-band radar (KAREN) together with high-resolution laser scanner measurements. Due to the limited time gap between the campaign phases it was impossible to transfer the ASIRAS radar from Iceland to Canada, and thus phase 2 did not include the ASIRAS radar. For future campaigns a combination of the two instruments are preferred.

The planned schedules were tight, especially during phase 1, leaving no room for delays. However, the weather was favorable and all planned flights were acquired. In general the instruments performed well. During test of the ASIRAS radar PC2 was not working, thus data was only acquired in Low Altitude Mode (LAMa). It was a challenge to keep up with the KAREN data backup due to the high along-track sampling rate (~30cm on the ground) resulting in a huge amount of acquired data. Another challenge was to keep the temperature of the KAREN instrument below the maximum allowed limit, especially during phase 2, where the instrument was mounted near the heater in the aircraft. In future campaigns these issues should be taking into consideration.

During the project new processing software for the KAREN data has been developed supporting routine processing. The processing chain is similar to ASIRAS SARIn acquisition in High Altitude Mode, which provides multi-looked echoes at a slightly coarser range-resolution than ASIRAS. The ASIRAS and ALS instruments worked well, and post-processed ALS data show results with mean elevation differences less than 6 cm and standard deviation within 6-10cm over flat areas at cross-over points. In the final processed data, KAREN data is noisier on the leading edge, when compared to ASIRAS.

First results of KAREN and ASIRAS differences over sea ice show about half the snow depth when compared to large scale in situ measurements taken in the Lincoln Sea. This is however, based on a simple TRMFA 50% for both radars, and needs further evaluation. Published results of the in situ data show overall good agreement with snow depths obtained using Warren climatology for this particular period and location. Quicklook data of snow depth obtained with NASA Operation IceBridge snow radar show results between in situ and KAREN-ASIRAS.

Over the EGIG line the in situ firn cores show good correlation with RACMO firn density model. Based on pRES and ASIRAS data the upper annual layers can be identified in the dry snow zone T19 and beyond with expected volume scattering down to 6 m at T19. Comparisons of absolute retracked KAREN and ASIRAS data needs further investigation.

A small study of NPI moorings of upward looking sonars located in the Fram Strait and ALS data from previous CryoVEx campaigns, results in total freeboard to thickness conversion factors between 5.32, 4.10, and 4.78 for the years 2014, 2015 and 2016. The inter-annual variations could be due to different snow depth, and could provide the inter-annual variations lacking in current snow depth climatologies such as Warren et al. (1999) and Forsström et al. (2011). Such combined datasets could be used to support conversion of ICESat-2 total freeboard into thicknesses. For future campaigns it should be prioritized to overfly more than one mooring and to align flight direction with local drift obtained prior to the flight.

With the CryoVEx/KAREN 2017 airborne campaign data the scientific community now has a unique collection of dual-frequency airborne and coordinated in situ measurements to validate the radar altimeter satellites CryoSat-2, Sentinel-3A and SARAL/AltiKa. The results of this campaign will assist on-going calibration and validation activities and support decision-making of future dual frequency satellite missions.

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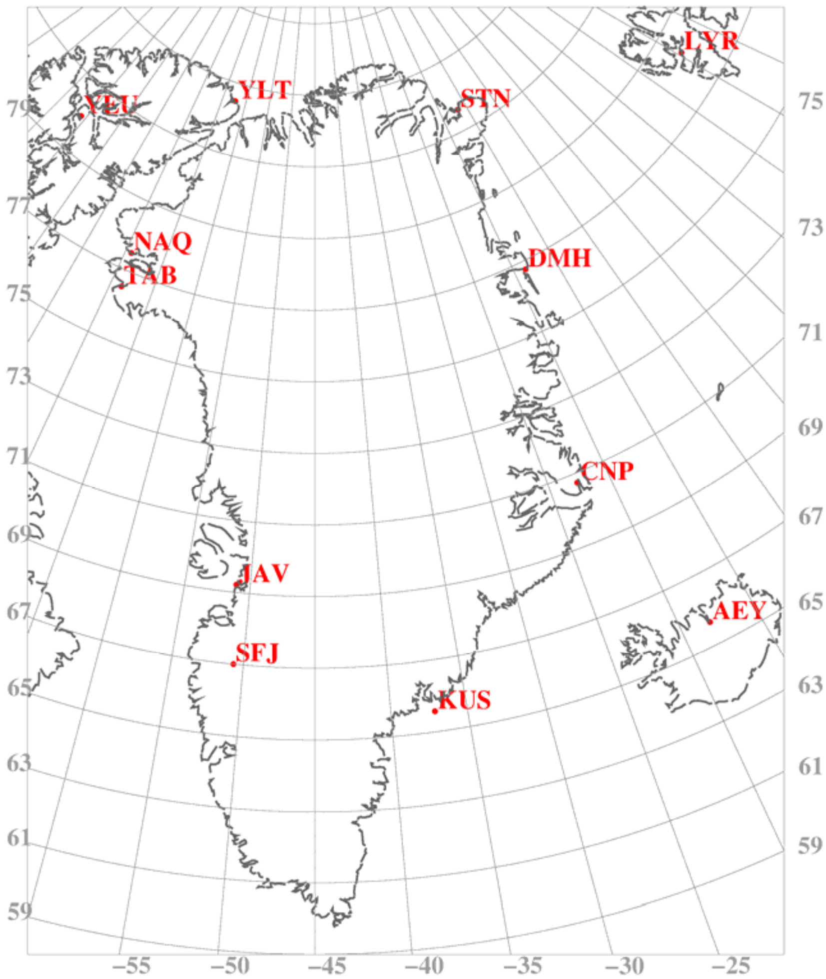
9 Appendix Airport codes

IATA		Location	Land	Latitude	Longitude
AEY		Akureyri	Iceland	65.659994	-18.072703
CNP		Constable Pynt	Greenland	70.7444	-22.6482
n/a	DMH	Danmarkshavn	Greenland	76.7704	-18.6581
JAV		Ilulissat	Greenland	69.217	-51.083
KUS		Kulusuk	Greenland	65.573611	-37.123611
LYR		Longyearbyen	Norway	78.2456	15.4991
NAQ		Qaanaaq	Greenland	77.50	-69.25
n/a	STN	Station Nord	Greenland	81.5971	-16.6569
SFJ		Kangerlussuaq	Greenland	67.006	-50.703
THU		Thule AB	Greenland	76.53	-68.71
YEU		Eureka	Canada	79.994444	-85.811944
YLT		CFS Alert	Canada	82.500	-62.325



10 APPENDIX Operator logs

DOY 077a, March 18, 2017: AEY-AEY, Test flight

ALS and ASIRAS:
12:21 Take off
Could not boot PC2. Several tries with different error messages, such as “No operating system found”.
After several tries, the PCs were shut down and we returned to AEY
12:52 Landing

DOY 077b, March 18, 2017: AEY-AEY, Test flight

ALS and ASIRAS:
16:07 Take off
After concluding that ASIRAS was working on PC1 alone, we returned to AEY.
16:23 Landing

DOY 078a, March 19, 2017: AEY - CNP

ALS:

First flight AEY-CNP
Calibration of ASIRAS over runway in CNP

09:07 Take off

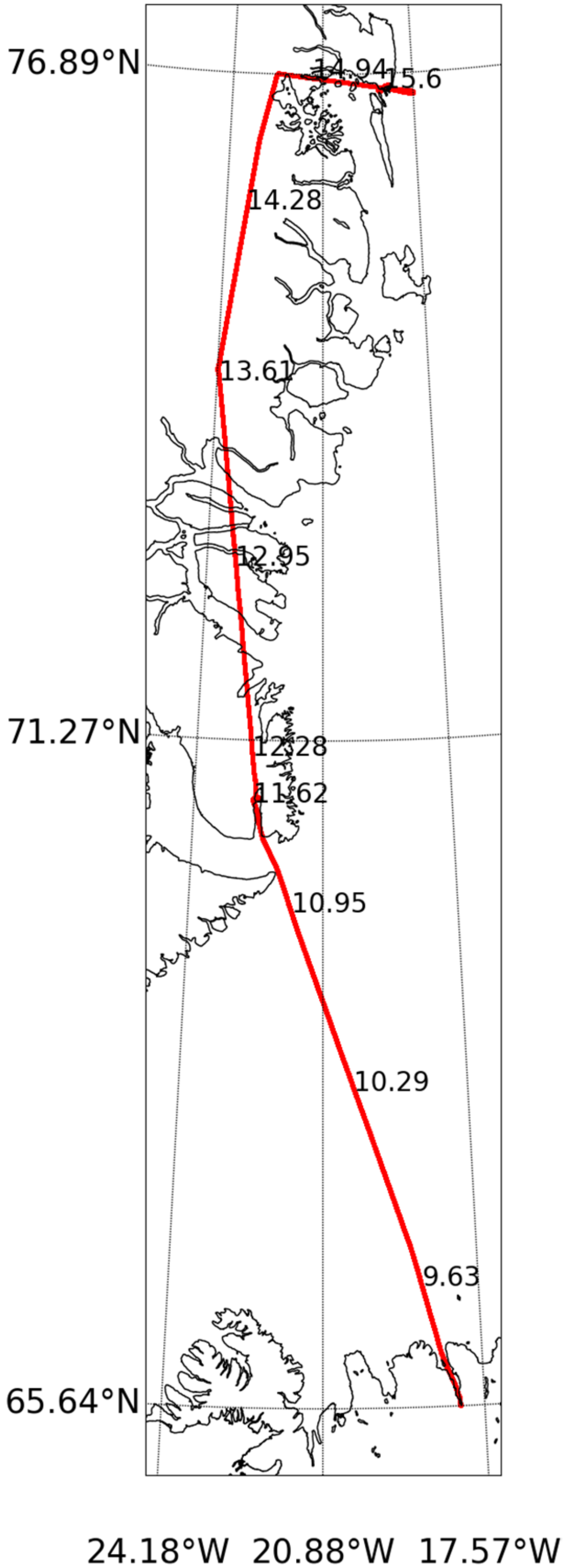
11:36 Landing CNP

ASIRAS:

09:07 Take off
Make short acquisition (*_00) to check, everything looks ok. 1 file collected
10:58 F4 LAM Calibration
11:10 start recording (*_01)

ASIRAS calibration measurements over runway in CNP:
Event 1: first overflight
Event 2: second overflight

11:27 Tried S SDS but error
11:29 stop recording (4 files collected)
11:30 F4 LAM Calibration
11:36 Landing CNP



DOY 078b, March 19, 2017: CNP - DMH

ASIRAS:

Second flight CNP-DMH
Measurements of Greenland ice sheet. Has been measured
several times before. Flight ended with 10 minutes of sea ice measurements.

12:04 Take off
13:28 F4 LAM Calibration
13:35: start recording (*_02)
14:51 Stop recording (16 files collected)
15:08 Start recording (*_03)

When trying to stop recording, the asicc program froze and
had to be shut down brute force. Files seem ok.
Not clear what the issue was.
4 files collected

15:33 landed DMH

DOY 079a, March 20, 2017: DMH – ULS – Tobias Ø - STN

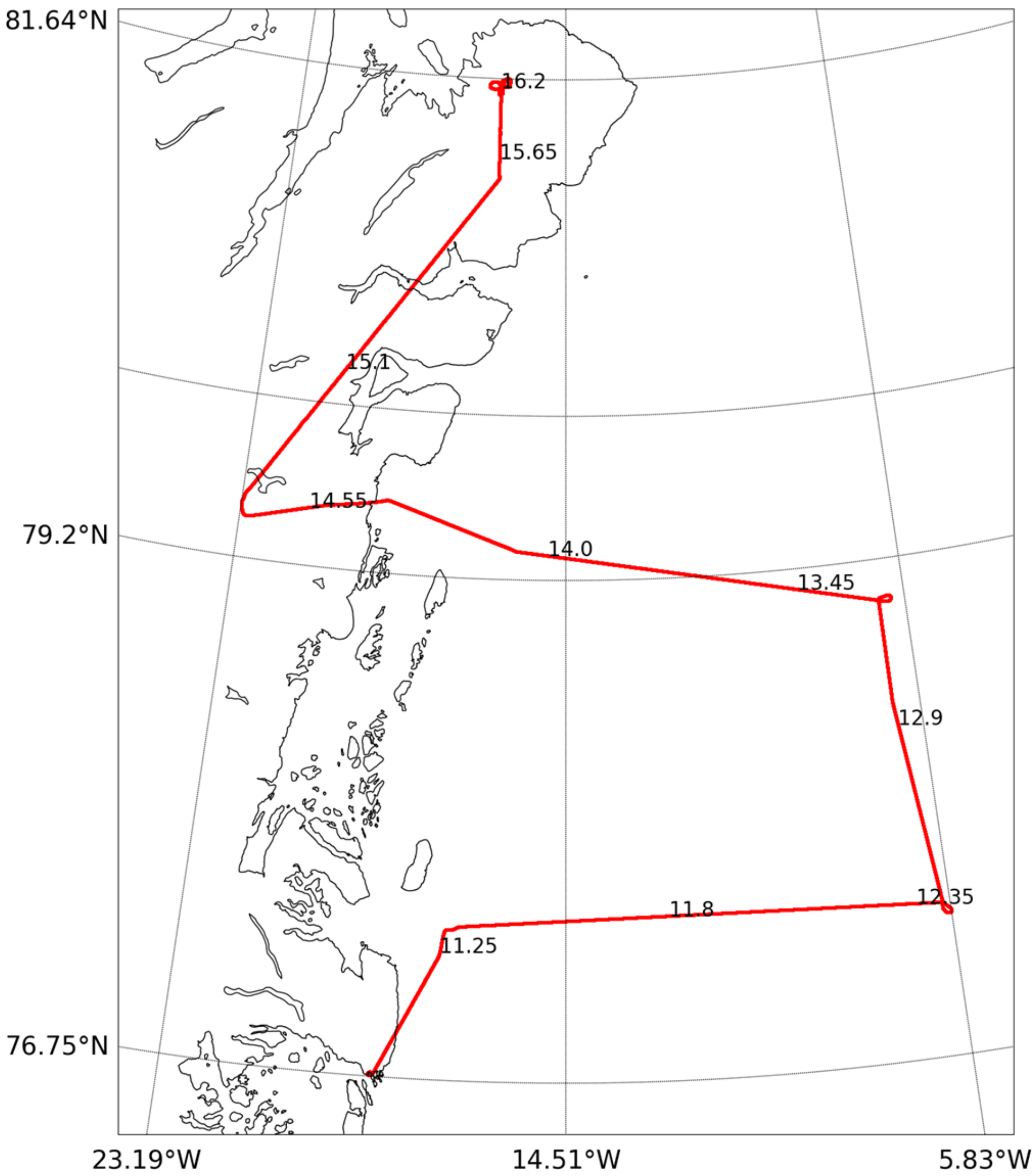
Measurements in Fram Strait over ULSs and end with measurements over 79fjord Glacier.

ALS:

1055	take off DMH
	Ka band not working
1214	new scan file
1323	-- -- --
14	Canon left side, 70 deg
1405	Tobias Ø
	Ka band working again, just before shoreline
1447	new scan file
1509	scanner stop, async error
1513	restart scanner, no return over Flade Isblink
1543	new scan file
1550~	Koldhallen
1603	landed STN

ASIRAS:

1055	Take off
1059	F4 LAM Calibration
1112	Star recording (*_00)
1443	Stop recording (43 files collected)
1445	F4 LAM Calibration
1603	Landing NRD



DOY 079b, March 20, 2017: STN – AltiKa - STN

Canon note: Canon time is wrong, but time of logged files are OK

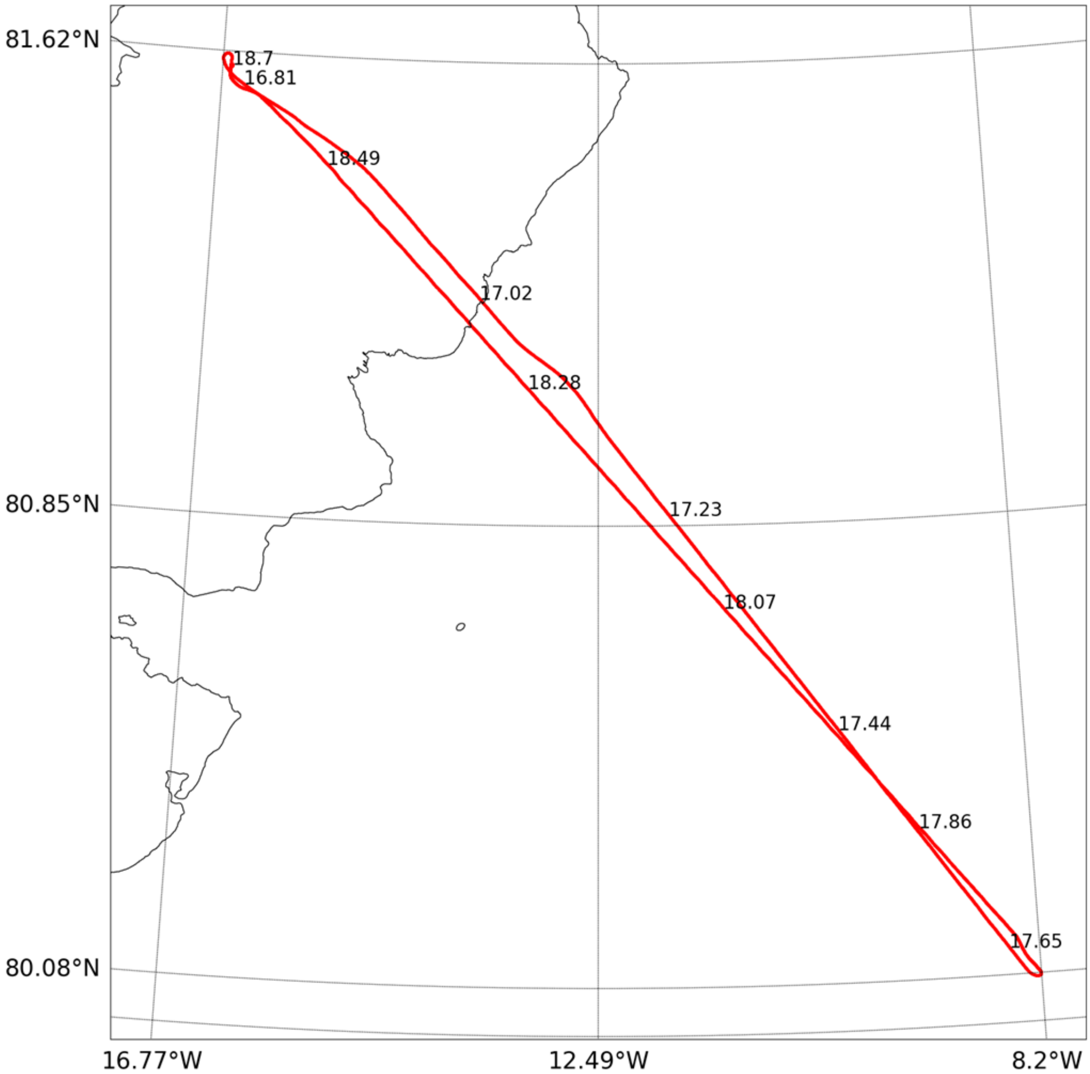
ALS:

1606	airborne
	Canon left, 70 deg
1836	landed STN

ASIRAS:

Measurements over Sea ice close to Station Nord. Waypoints chosen based on satellite images of sea ice cover and drift and Altika predicted orbits. Varying sea ice conditions along line.

1645	Take off
1652	F4 LAM Calibration
1706	Start recording (*_01)
1740	Stop recording (7 files collected)
1742	F4 LAM Calibration
1836	Landing NRD



DOY 080a, March 21, 2017: STN – CS2 - STN

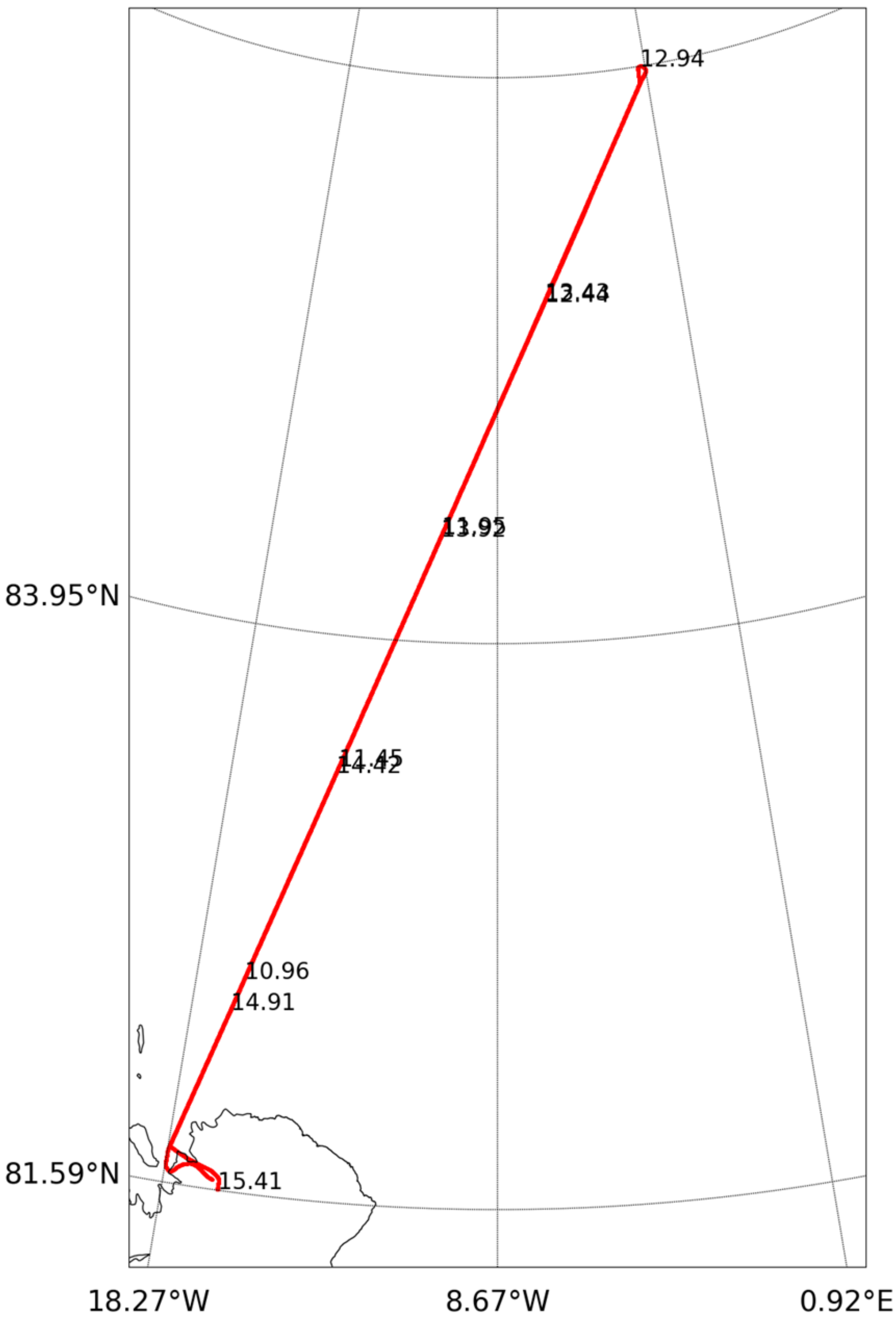
ALS:

	CS2 line
1025	take off STN
	EGI lost satellites, power failure, IMAR ok
1230	Canon shut down, connection problems
1254	turning at N 86 16. W 0 35.1
1255	Canon started again
1521	landed

ASIRAS:
First flight NRD-NRD.

Measurements along CS2 track, track number ??.
Measures the CS 2 track in both directions.

1026	Take off
1029	F4 LAM calibration
1031	Start recording (*_00)
~ 1254	End of line. Teardrop turn to return via the same WPs back.
1456	Stop recording (54 files collected)
1457	F4 LAM calibration
1521	landing NRD



DOY 080b, March 21, 2017: STN – Triangle - STN

Canon note: Canon time is wrong, but time of logged files are OK
adjust Canon time for next flights

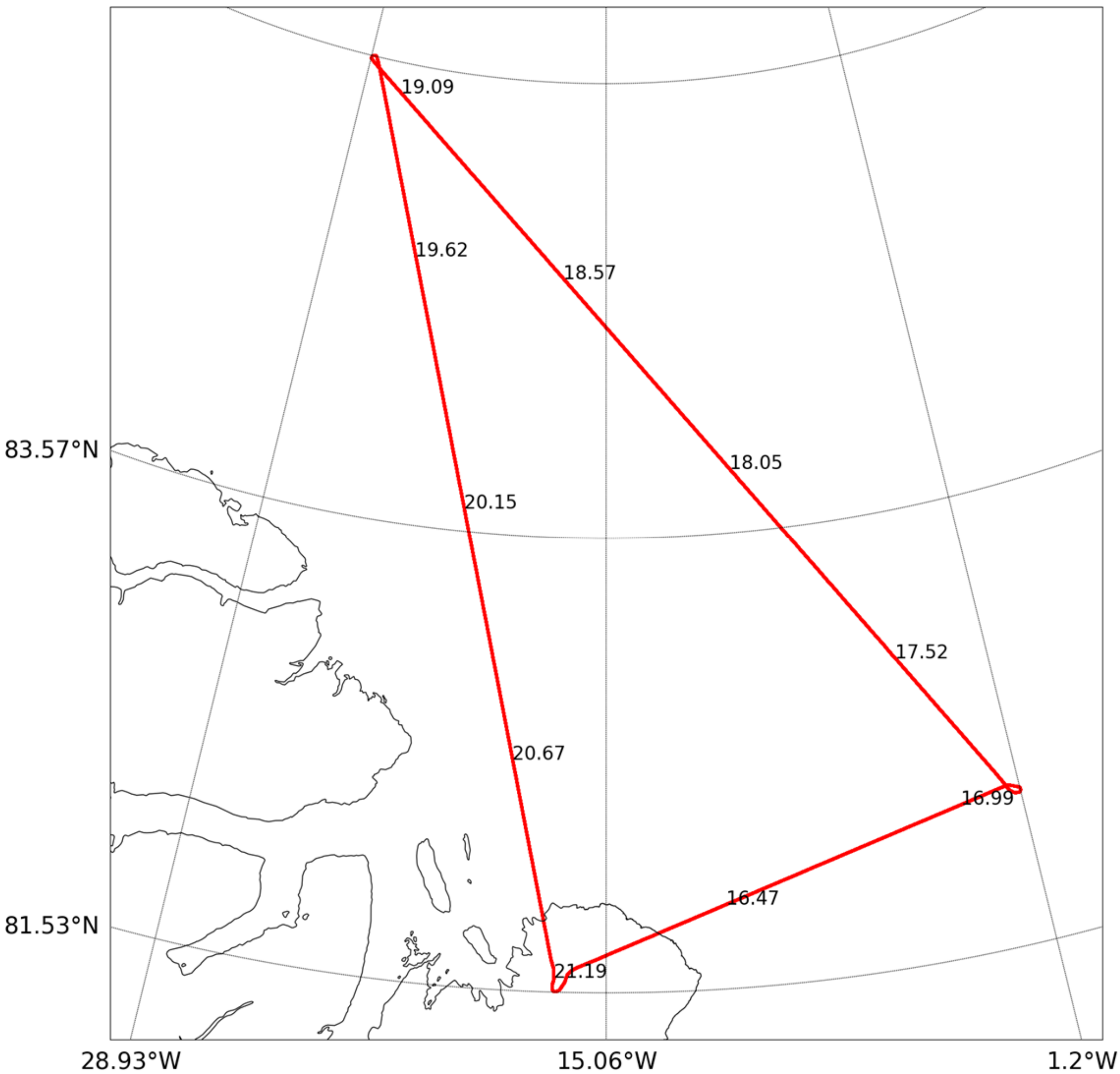
ALS:

1601	airborne F-line
1845	Canon right side 50 deg
1935	Canon left side 70 deg
1949	Canon stopped, too dark
2108	landed

ASIRAS:

Second flight NRD-NRD.
Measurements in a triangle out of NRD. Has been measured several times earlier.

1601	Take off
1603	F4 LAM Calibration
1605	start recording (*_01)
2038	Stop recording (55 files collected)
2038	F4 LAM Calibration
2108	Landing NRD



DOY 081, March 22, 2017: NRD – Independence Glacier - YLT

ALS:

1423	airborne
1455	Canon right side 50 deg, time is correct
1812	landed Alert

note:
rear antenna issues from beginning.
1) Ka unstable sats
2) air4 no sats, replace cable
3) air3 few sats, check cable
seems air3 cable has been unplugged from splitter the day???

also issues with EGI sats, but EGI on front antenna.

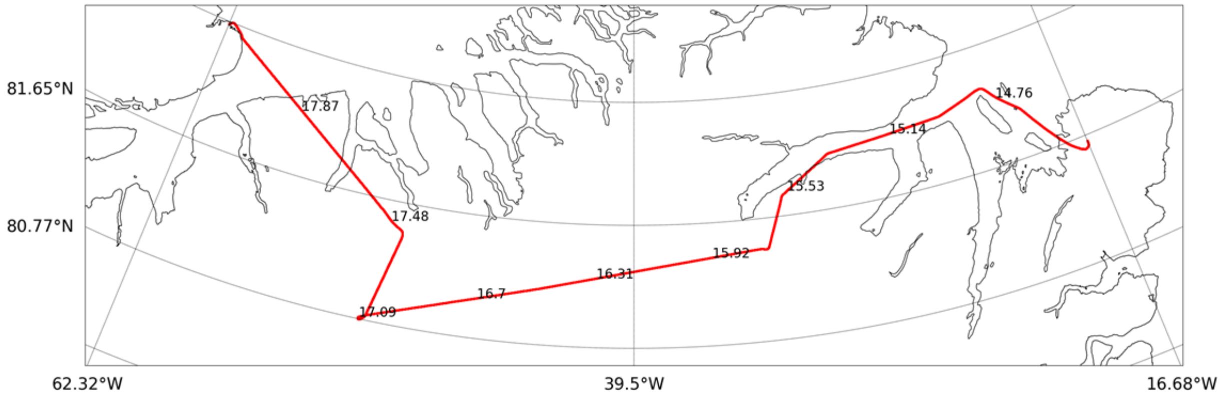
ASIRAS:

NRD-Alert.
Measurement in the Independence Fjord, over the Greenland Ice sheet and to Alert.

On ground Alert: some issues occurred with the GPS signal/cables and this delayed departure.

1423	Take off
1430	F4 LAM Calibration
1440	start recording (*_00)
1718	stop recording (32 files collected)
1719	F4 LAM Calibration
1812	Landing Alert

Note ! It is not possible to collect SDSs (short data selections). Unclear what the problem is, but assume it is due to the missing PC2.



DOY 083, March 24, 2017: YLT – CS2 - YLT

CS2 track, On track during satellite pass
NASA P3 and Polar 5 on track as well
POF just behind Polar 5 until satellite pass

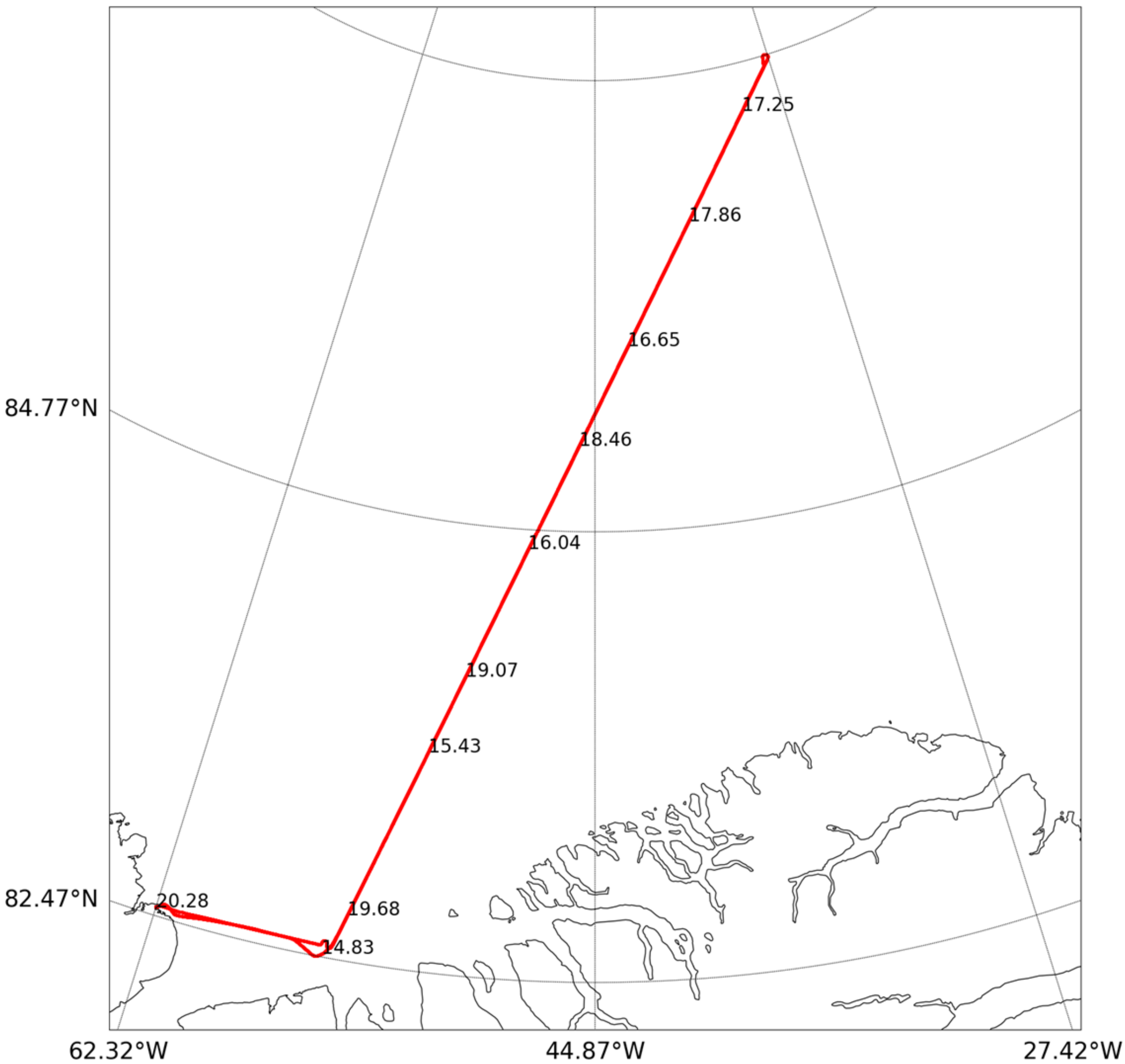
ALS:

1422	airborne
1455	Canon left side 50 deg, time is correct
1600	NASA P3 overhead going south Polar 5 <8 nm ahead of POF, reduced to 1 nm when satellite passes 16:41
1641	CS2 pass, POF just behind Polar5
1642	Polar5 breaks off to the west
1721	87N turn around iMAR disconnected power, for how long???
1812	iMAR restarted
2012	landed

ASIRAS:

Alert - CS2 - Alert
Coordinated measurements along CS2 track together with OIB and AWI. CS2 track number 36892.

1223	Take off
1426	F4 LAM Calibration
1428	Start recording (*_00)
1945	stop recording (64 files collected)
1946	F4 LAM Calibration
2011	Landing YLT



DOY 086, March 27, 2017: YLT – CS2 – in situ line - YLT

C.Haas +CS2 track, On track during satellite pass
17:26

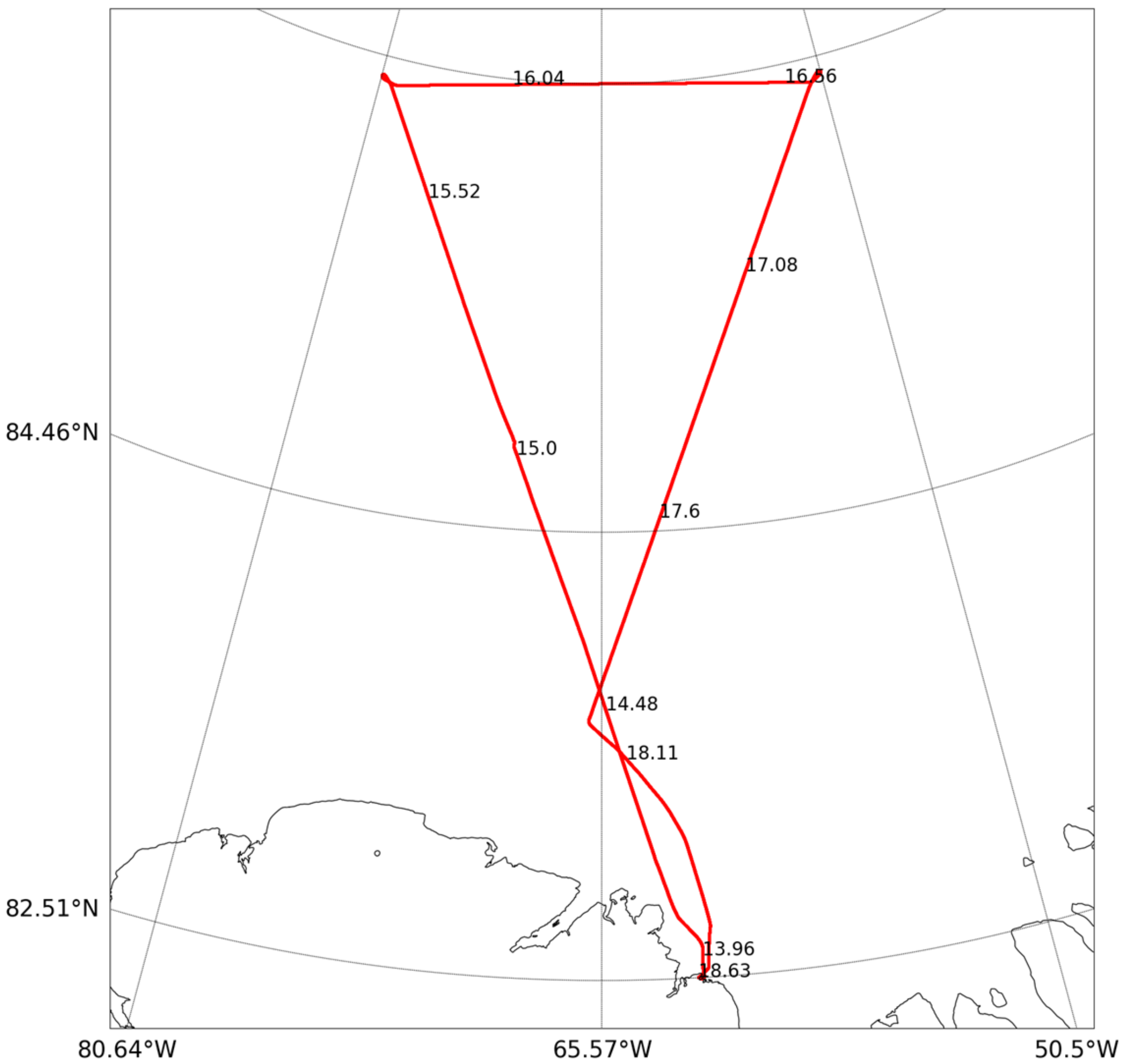
ALS:

1354	airborne
	Canon left side 50 deg, time is correct
1427	air1 start logging
1430	scanner async error
	restart and synch
1525	Canon shut down, bad visibl
1548	Canon on again
1748	Canon shut down, bad visibl
1800	break line, turning towards Alert,
	strong wind,
	snow drift in Alert
1834	landed

ASIRAS:

Alert - NW line – CS2 track – Alert
Measured along a line going NW suggested by Christian Haas. Returning to Alert via CS track number 36936.

1353	Take off
1356	F4 LAM Calibration
1359	Start recording (*_00)
1726	CS2 pass
1801	Break away from line due to poor visibility
1817	Stop recording (52 files collected)
1818	F4 LAM Calibration
1334	Landed Alert



DOY 087, March 28, 2017: YLT – Peterman – GrIS - TAB

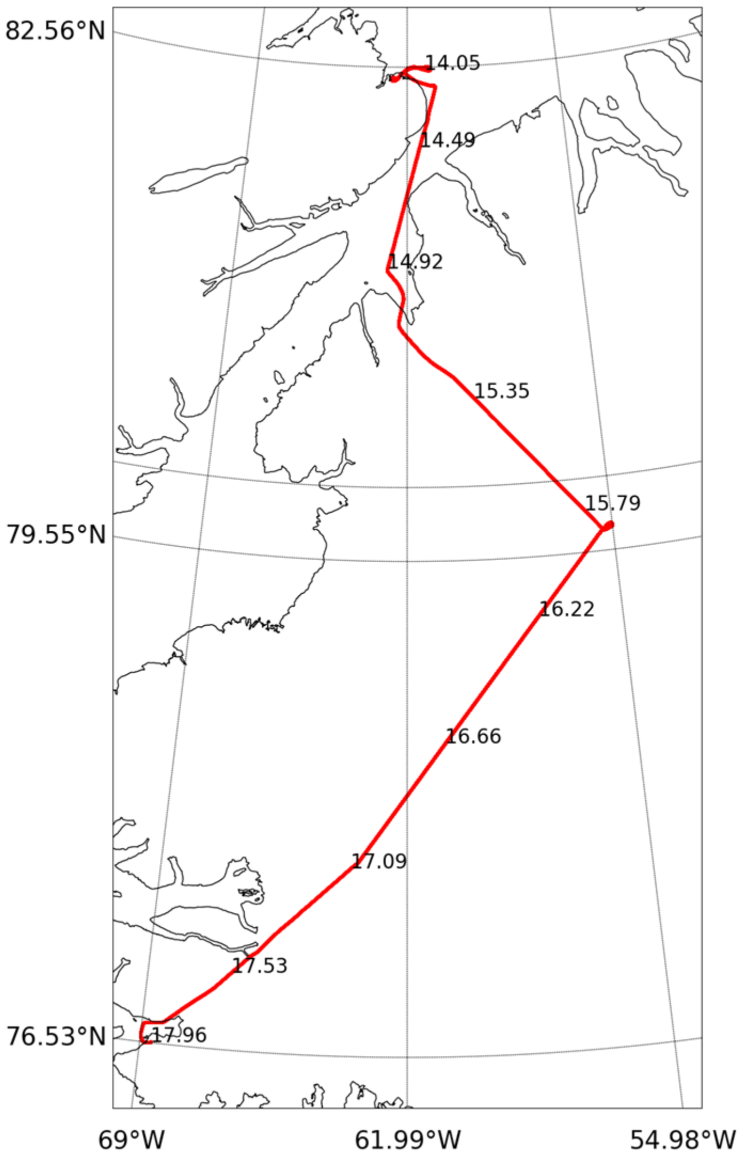
ALS:

1356	airborne
1407	calib runway + spinaker
	Canon right side 60 deg, time is correct
1427	air1 start logging
1445	climb due poor visibl
1455	stop canon due bad visibl
1500	descend to 1200 ft, canon started again
1501	off track due weather, canon shut down
1600	canon started again
1753	landed Thule

ASIRAS:

Alert – TAB
Via Greenland Ice Sheet, Petermann Glacier

1356	Take off
1357	F4 LAM Calibration
1359	Start recording (*_00)
	Calibration over runway:
	Event #1 : First runway overflight
	Event #2 : Second runway overflight
1446	Stop recording (10 files collected)
	Had to climb due to clouds
1518	Start recording (*_01)
	Petermann
1718	Stop recording (25 files collected)
1719	F4 LAM calibration
1752	Landed TAB



DOY 088, March 29, 2017: TAB – Sentinel-3A – Devon - TAB

ALS:

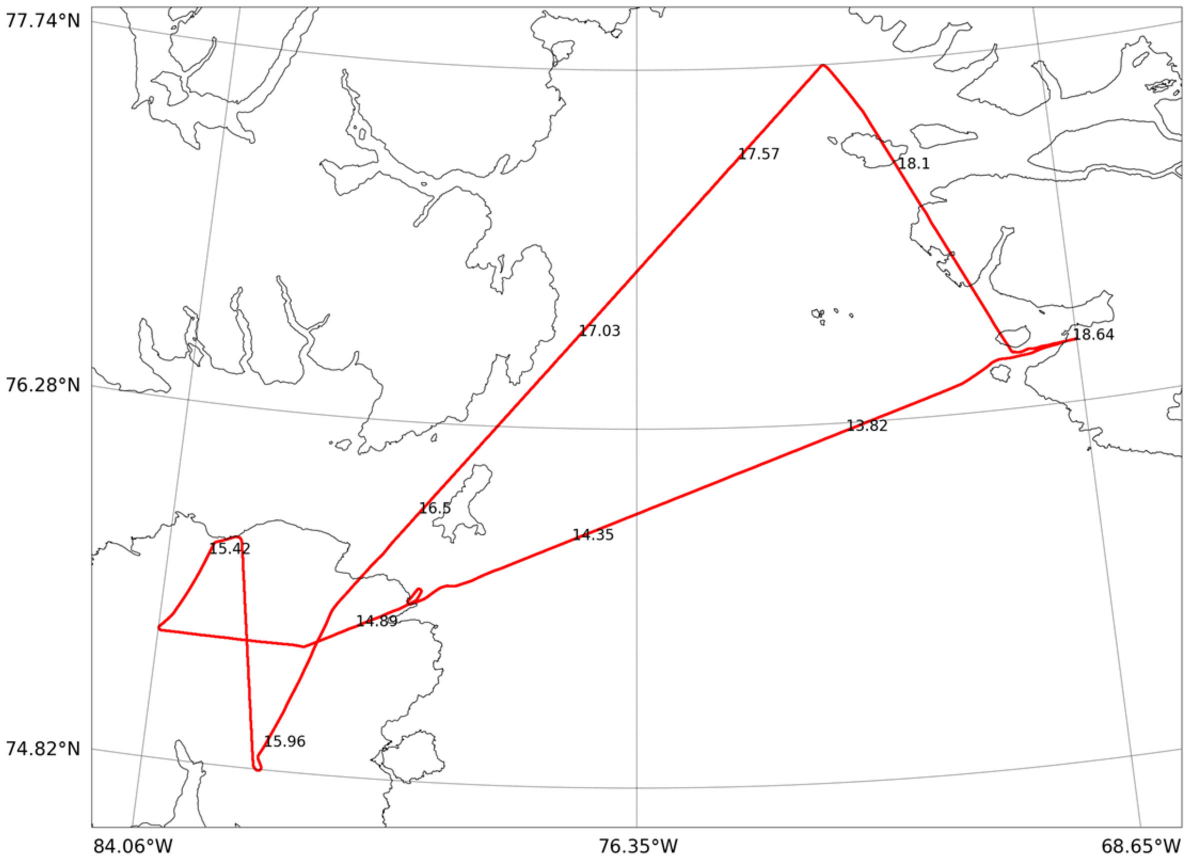
1322	airborne
1334	canon right side 60 deg
1402	canon off, batt low
1420	canon on again
1433	climb due clouds near devon
1438	down again
	devon flown 360-800 m clearance
1610	canon left side 50 deg
	scanner not logging 1554-1635
1838	landed

ASIRAS:

TAB – TAB

Flight over Devon Ice Cap. Return to TAB via Sentinel-3 track

1322	Take off
1324	F4 LAM Calibration
1325	Start recording (*_00)
	Line directly to Devon
1434	Stop recording (14 files collected)
	Had to climb due to clouds
1438	Start recording (*_01)
1442	Stop recording (1 file collected)
	Had to break line and climb due to strong turbulence near Devon
1448	Start recording (*_02)
1451	Stop recording (1 file collected)
1452	Start recording (*_03)
1523	Stop recording (7 files collected)
1530	Start recording (*_04)
	Devon Ice Cap
1617	Stop recording (10 files collected)
	Align with/descend to Sentinel-3 track from Devon Ice Cap
1620	Start recording (*_05)
	On S-3 track
	Event #1 S-3 overpass
1751	Stop recording (19 files collected)
1751	F4 LAM Calibration
1837	Landed TAB



DOY 089a, March 30, 2017: TAB – Baffin Bay – Disko - JAV

ALS:

1149	airborne
1220	on line
	canon right side 60 deg
1402	async error closing file, scanner restarted
1540-1555	clouds over disko, no laser
1618	landed jav

ASIRAS:

TAB – JAV

Measure over sea ice from TAB to Disko Island.

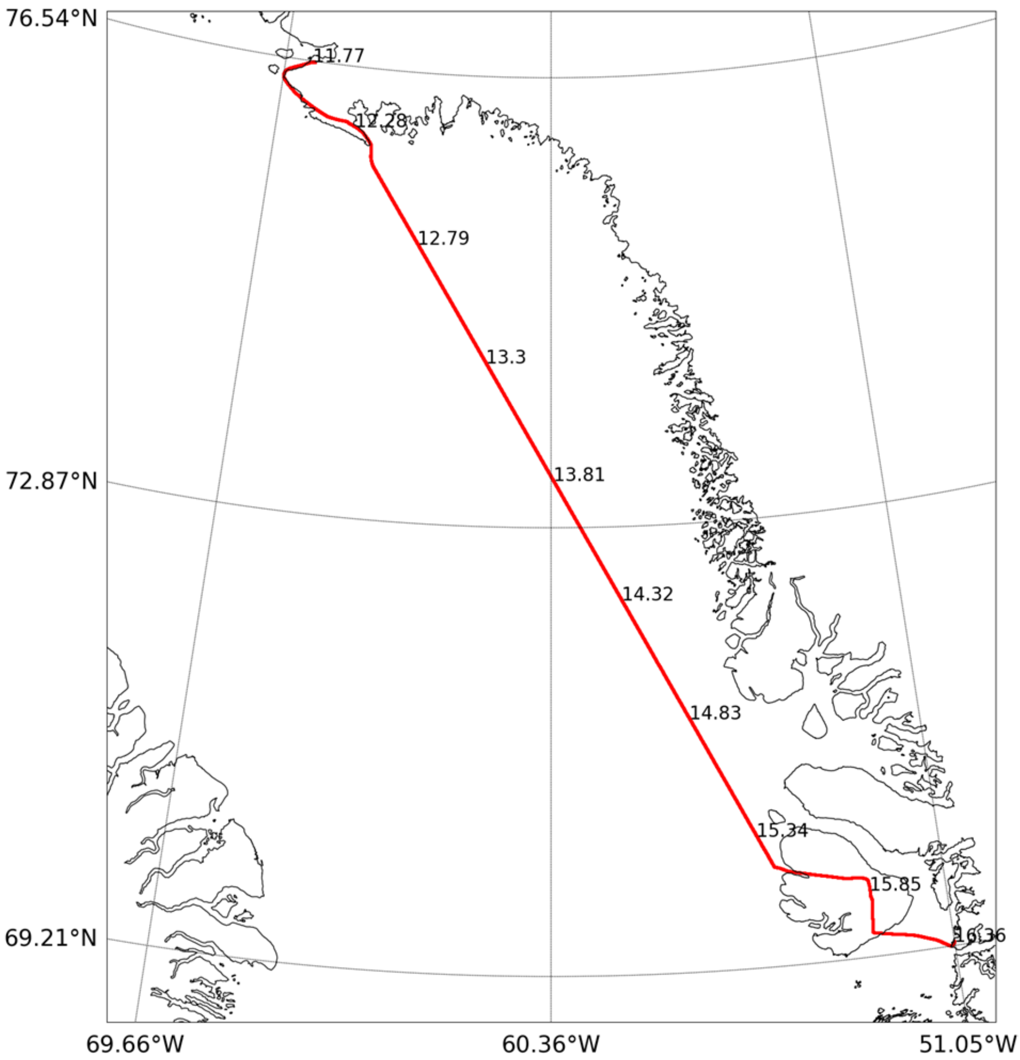
Measurements over Disko (but limited due to clouds).

1149	Take off
1154	F4 LAM Calibration
1158	Start recording (*_00)
1207	Stop recording (2 files collected)
1223	Start recording (*_01)
	on line to Disko
1527	Stop recording (37 files collected)
	climb for track on Disko
1550	Clouds over Disko Island.
1553	Start recording (*_02)
	Disko
1559	Stop recording (2 files collected)
1601	F4 LAM Calibration
1618	Landed JAV

DOY 089b, March 30, 2017: JAV - JQA

ALS:

1645	airborne jav
1729	landed Qaarsut



DOY 090a, March 31, 2017: JQA – AltiKa -JQA

snow, low visibl, delay dep

ALS:

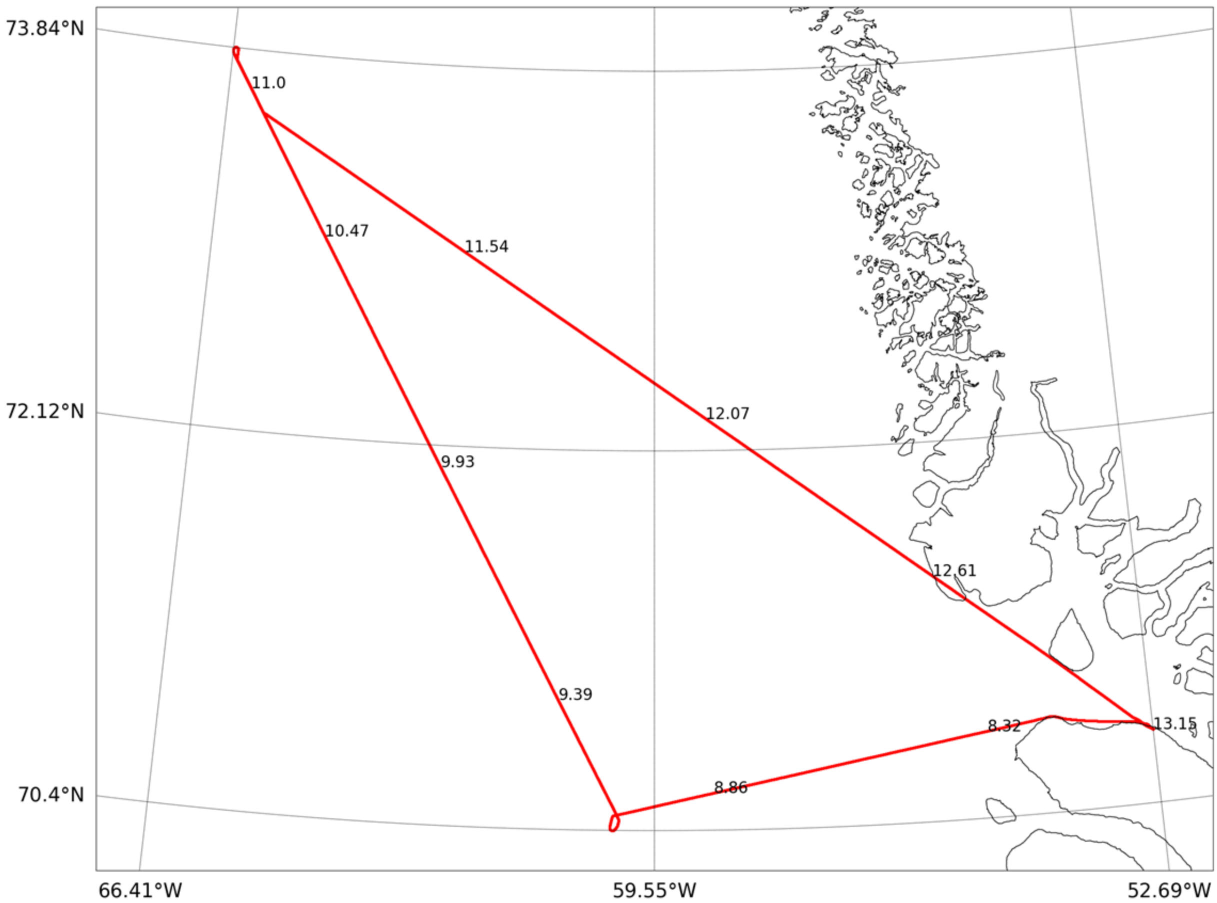
0800	airborne
0905	canon left 60 deg
0936	canon off, fog
0956	canon on
1057	end of line, backtrack 5 min
1103	towards Qaarsut
1208	landed

ASIRAS:

Qaarsut-Altika track - Qaarsut

Measure over Altika track (0.5 hours after satellite)

0800	Take off
0909	F4 LAM Calibration
0900	Start recording (*_00)
0907	On Altika track
1103	Stop recording (25 files collected)
	Return to Qaarsut
1104	F4 LAM Calibration
1307	Landed Qaarsut



DOY 090b, March 31, 2017: JQA – EGIG in situ - JQA

ALS:

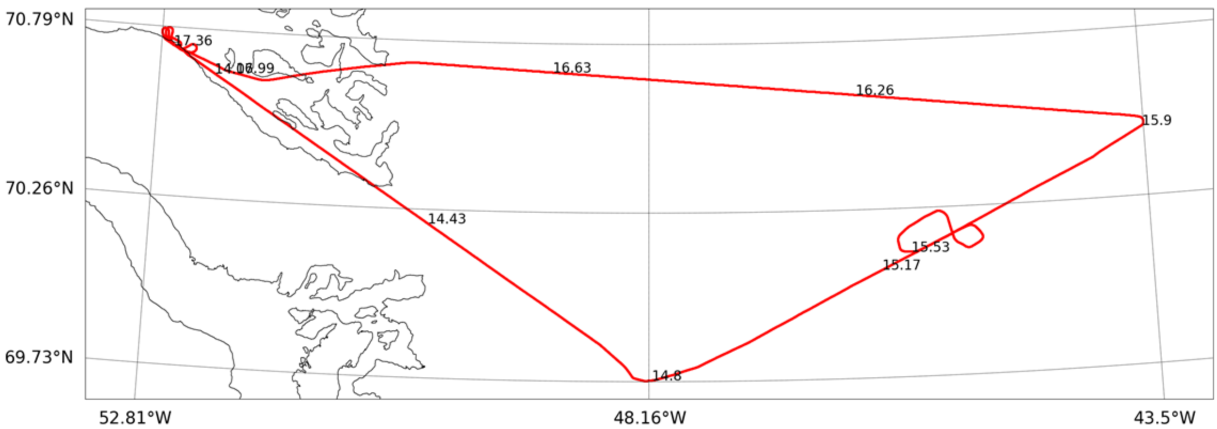
EGI not aligned, cannot wait, IMAR semi aligned

1352	take off
1415	EGI ok, fom=117
1520-1530 3	passes of T12, people on ground
	imar says logging ok, but only little data, no more logging, memory full?
1706	runway+building calibration
1720	landed JQA

ASIRAS:

EGIG line T1-T19, overfly ground team on T12.

1358	Take off
1406	F4 LAM Calibration
1436	Start recording (*_01)
1555	Stop recording (16 files collected)
1700	Start recording (*_02)
	Calibration flight over runway in Qaarsut. Two directions.
	Event #1: first pass over runway
	Event #2: second pass over runway
1709	Stop recording (2 files collected)
1709	F4 LAM Calibration



DOY 091a, April 1, 2017: JQA – EGIG - CNP

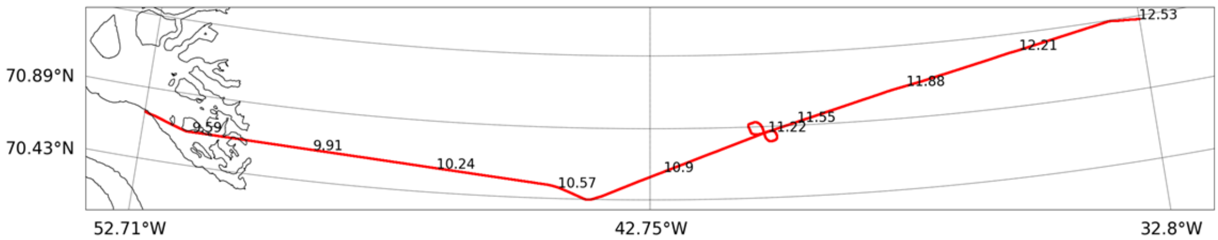
ALS:

0925	airborne
1112	overhead other TO
1347	landed CNP
1411	airborne
1621	landed AEY

ASIRAS:

Measure over EGIG line from T19 towards East. Ground team overflight at point C30 (between T21 and T41)

0924	Take off
1009	F4 LAM Calibration
1032	Start recording (*_00)
~1120-11:27	ground team overflight
1228	Stop recording (24 files collected)
	head for CNP
1229	F4 LAM calibration



DOY 091b, April 1, 2017: CNP - AEY

No surveying

DOY 95, April 5, 2017: YCB-AltiKa-YCB

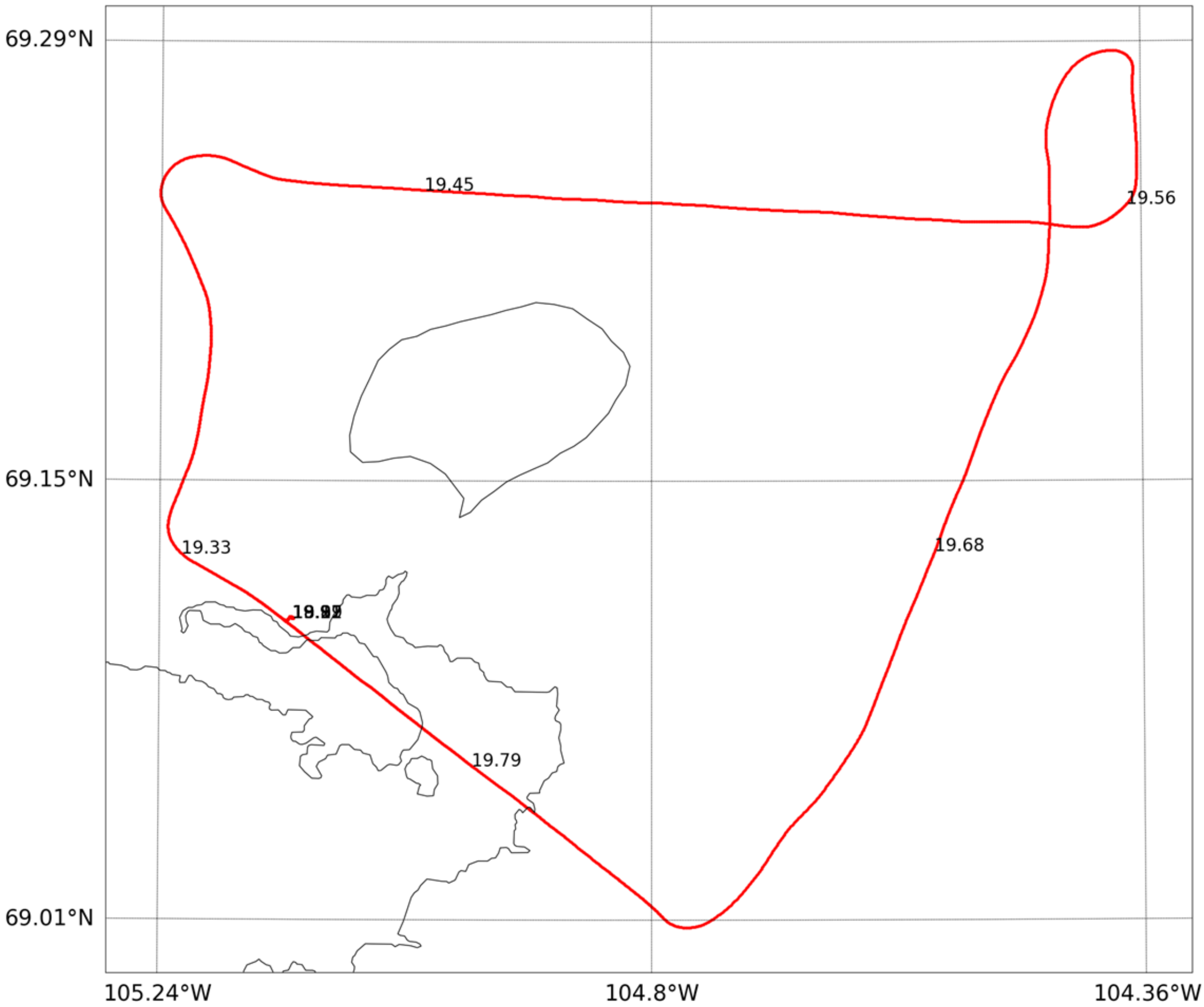
ALS + KAREN:

1906 Ready

DOY 97a, April 7, 2017: YCB-TER-YCB

ALS + KAREN:

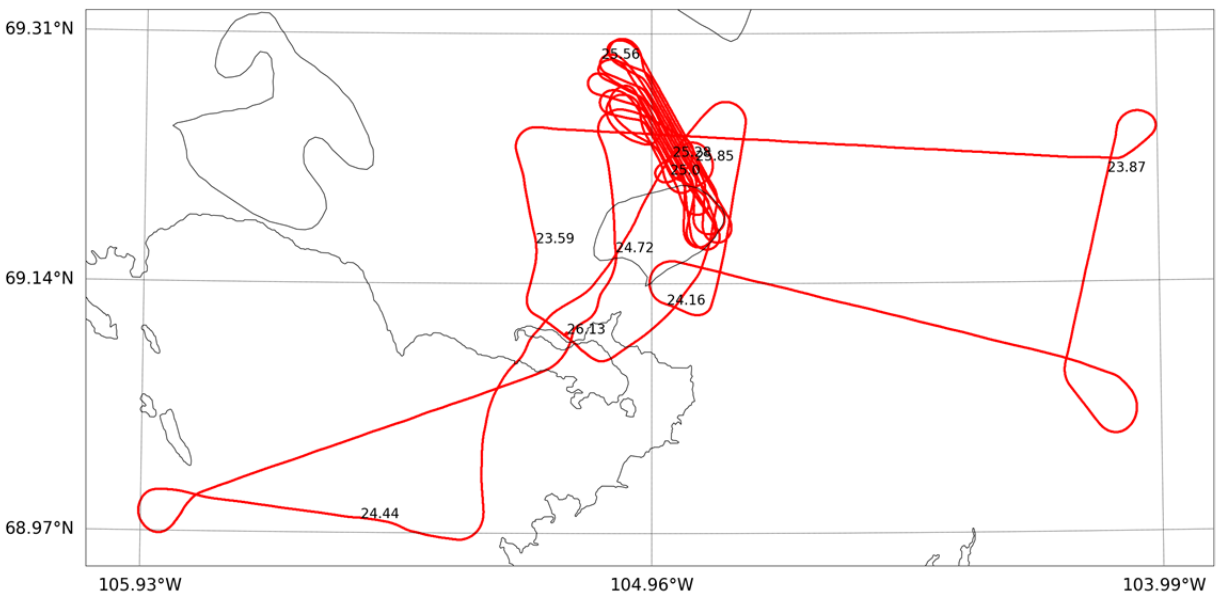
1906 Ready
1914 Taxi
1918 Take-off
1925 Start camera logging, start Ka-band radar
1933 Low clouds, stop surveying
1951 On ground



DOY 97b, April 7, 2017: YCB-TER-SI-YCB

ALS + KAREN:

2329	Taxi
2332	Take-off
2334	Ka test file, OK
2338	On the line, start Ka-file + DSLR
2352	New line, new Ka-file + DSLR
235908	New line
001000	Crossing of lines
0014	Go for 3 sea ice lines, no reflectors
0020	Start logging Ka-file + DSLR
	Sea ice
003214	New line, new Ka-file + DSLR
	Some low clouds on the last sea ice line
0040	End of sea ice line
005230	New line Terrestrial survey, New Ka-file
0059	New Ka-file
010606	New Ka-file
011522	New Ka-file
012501	New Ka-file
013345	New Ka-file
014359	New Ka-file
015441	New Ka-file
0204	On ground

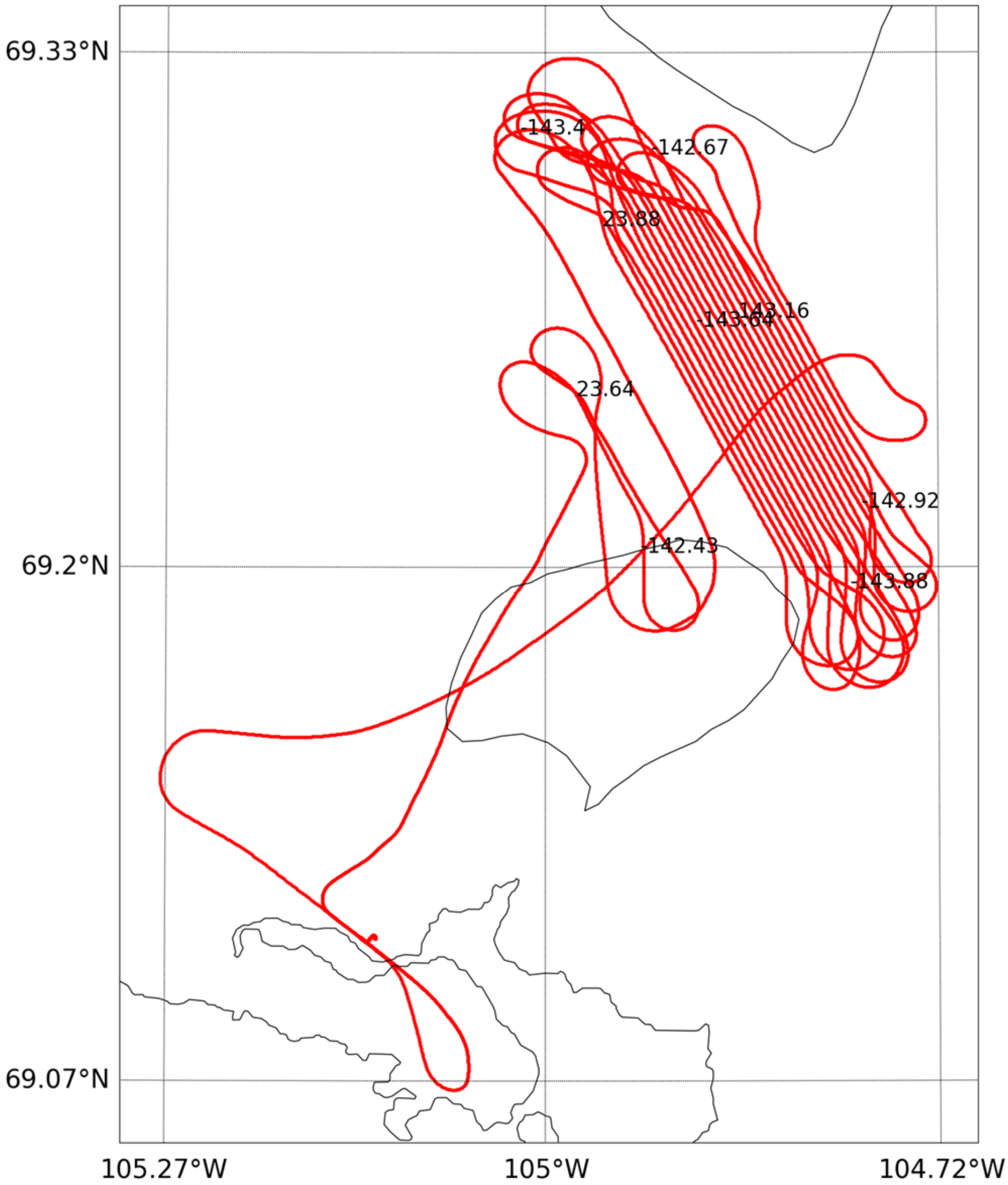


DOY 98, April 8, 2017: YCB-TER-YCB

Drifting snow

ALS + KAREN:

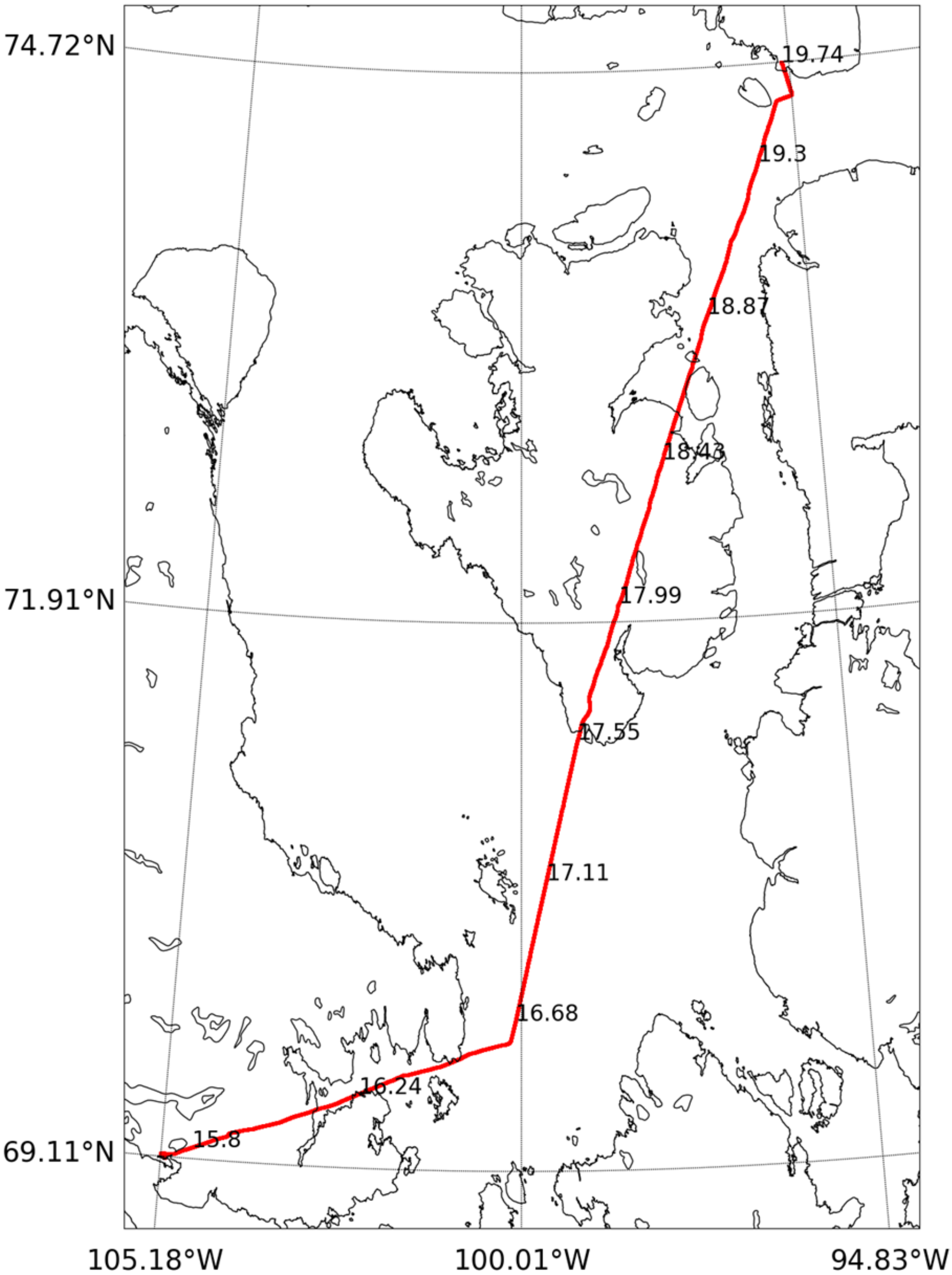
2327	Taxi
	Take-off
233452	Ka test file, OK
233822	On the line, 1
	On the line, 2
234709	New Ka-file, on line 3
235235	New Ka-file, on line 4
000242	New Ka-file, on line 5
001426	New Ka-file, on line 6
	Tka=60C, turn down heat
002539	New Ka-file, on line 7
003055	New Ka-file, on line 8
003725	New Ka-file, on line 9
004226	New Ka-file, on line 10
004933	New Ka-file, on line 11
005356	New Ka-file, on line 12
010020	New Ka-file, on line 13
010432	New Ka-file, on line 14
011044	New Ka-file, on line 15
011502	New Ka-file, on line 16
012017	New Ka-file, on line 17
012403	New Ka-file, on line 18
013235	New Ka-file, on line 19
	Crossing lines en route YCB
0139	Runway overflight
	On ground



DOY 101, April 11, 2017: YCB-McClintock-YRB

ALS + KAREN:

1536	Ready
1538	Taxi
1540	Take-off
154807	Ka test file, OK
	At high level until first WP in McClintock channel
	Leaving the scanner logging, out of range
163647	Descending, start logging Ka-file, start DSLR
	WP1
	Ka-radar PC went to sleep, but still logging
165356	New Ka-file
171327	New Ka-file
1733	End of line
171327	Keep on the line, new Ka-file
1736	Over land, stop logging Ka + DSLR
1753	Stop logging ALS
	On ground YRB

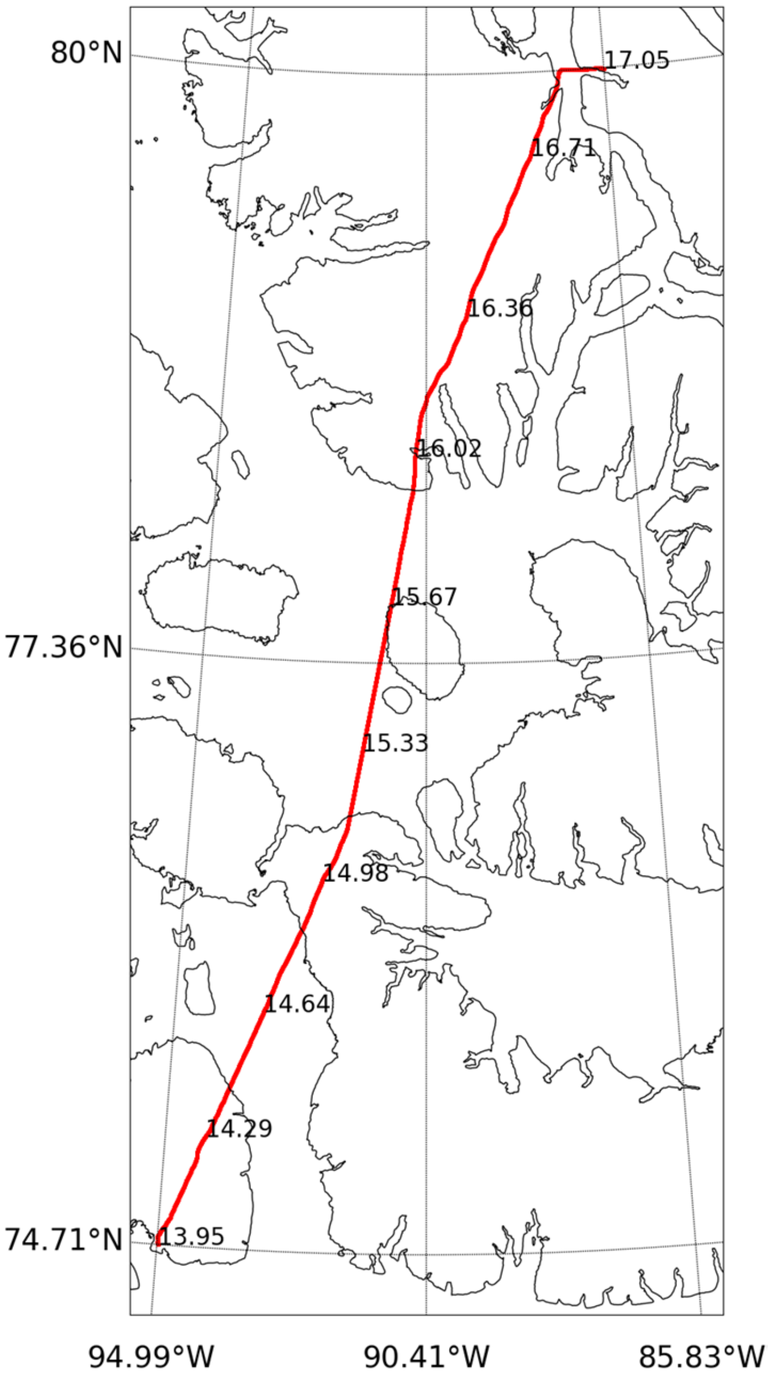


DOY 102a, April 12, 2017: YRB- C1-C2-C3-YEU

Old CS-2 track from 2014

ALS + KAREN:

1346	Ka-band radar + EGI, OK
	ALS + DSLR laptops too cold
1350	Taxi
	Take-off
1412	ALS and DSLR laptops up and running
141231	Test of Ka-band radar, OK
	Download EGI, missed 110
1454	Approaching C1, Start ALS logging
	Low ground speed 96kn
1508	On the line
151015	Start logging Ka-file + DSLR
152000	New Ka-file
1539	Over land, island
153937	New Ka-file
1555	Stop logging Ka-file, ALS, DSLR
~1702	On ground YEU

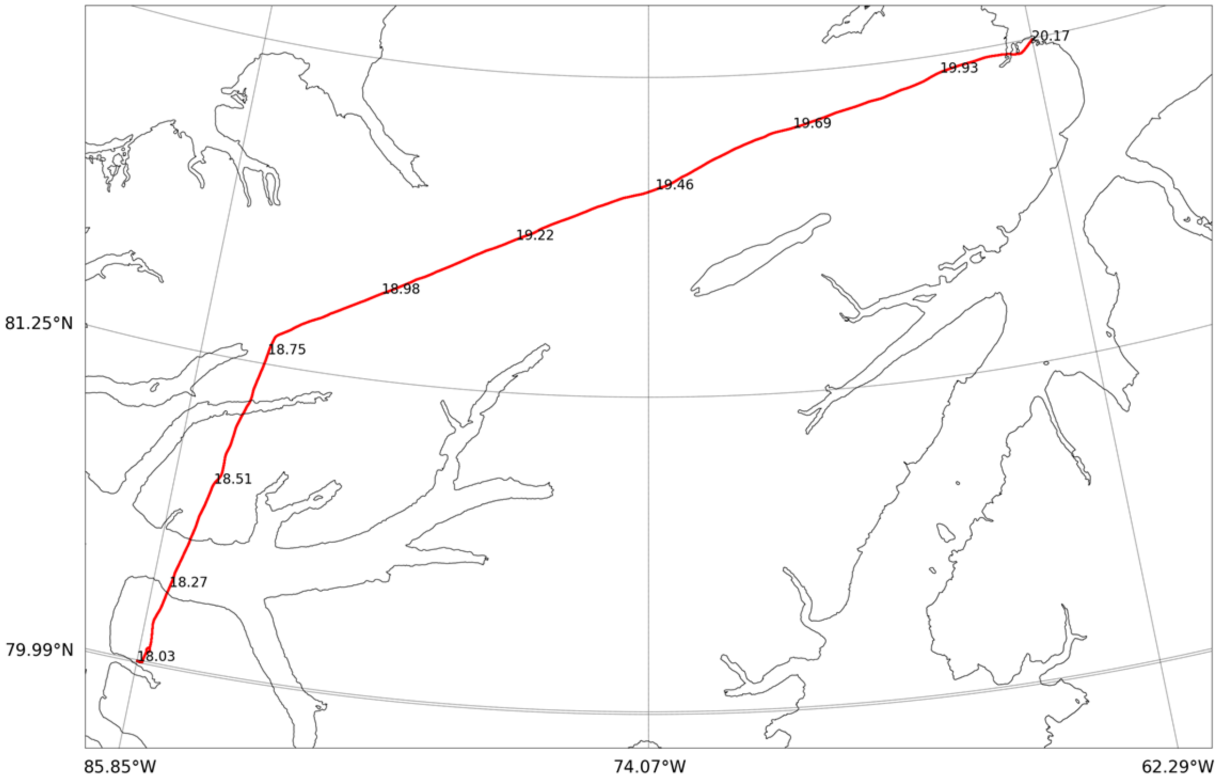


DOY 102b, April 12, 2017: YEU- Gline-YLT

Old track from 2012

ALS + KAREN:

	Started to taxi before EGI aligned
	New alignment
1800	Problems with ALS, all red
	Taxi
	Take-off
1845	Tka=69C, Shut down system
	Got ALS synchronized using RiTerm, all OK
20…	On ground YLT

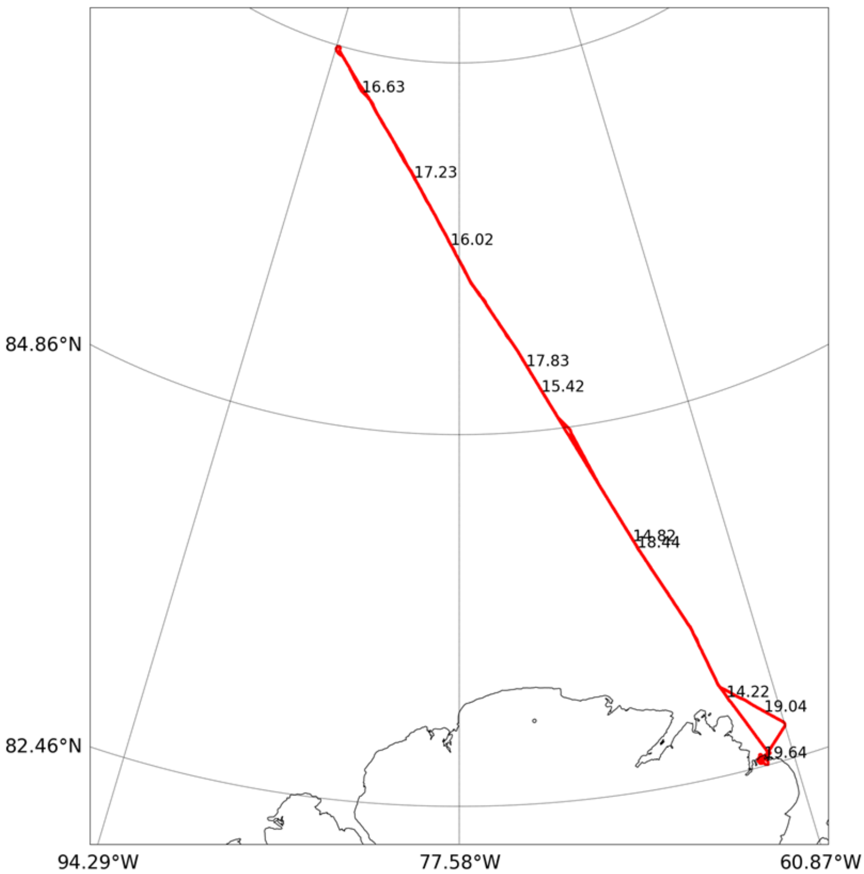


DOY 103, April 13, 2017: YLT- InSitu-YLT

ALS + KAREN:

Following CS-2 track 73159 from April 12, 02 UTC. Modified to overfly already surveyed in situ sites (2,3,7,8)
In situ team on ground point IS05, landed when we passed first time

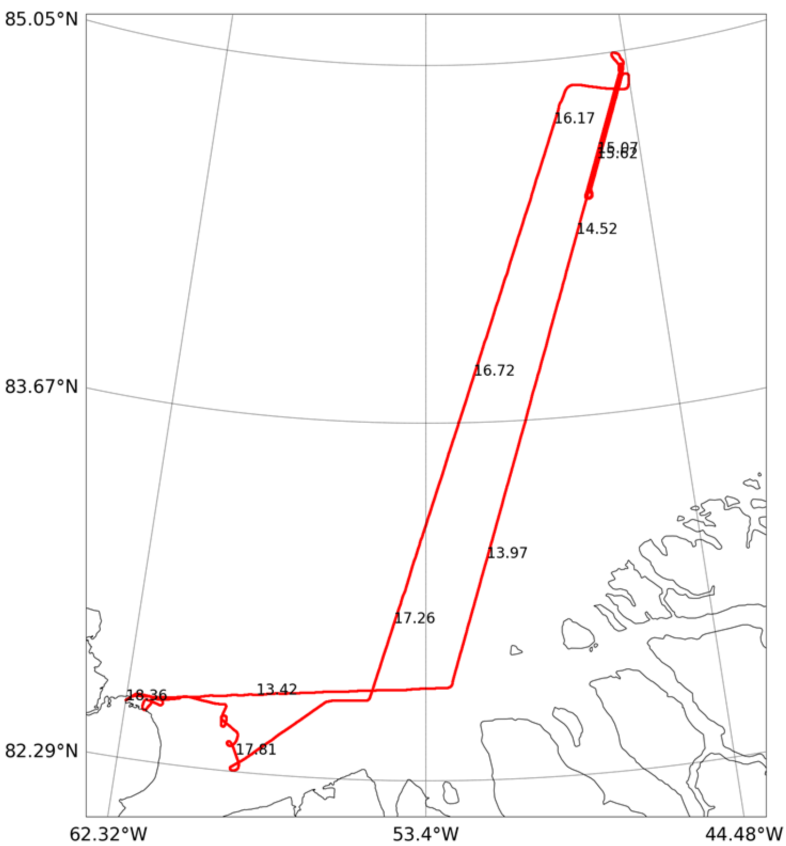
1355	Ready to taxi
	Camera PC not working
	Installed AIR2 as a spare GPS, same splitter as OxTS INS ?
1358	Take off
140145	New Ka-file
1420	No survey due to clouds
142703	New ALS + Ka-files
143800	New Ka-file, ~200m due to low clouds
144901	New Ka-file
145841	New Ka-file
150842	New Ka-file
1518	IS05E
151836	New Ka-file
1530	Camera running on my personal laptop
153342	New Ka-file
154804	New Ka-file
1553	IS06F
1555	Clouds
1608	Passing IS08H
160957	New Ka-file
	New camera session, 500 pix
162910	New Ka-file
164136	IS10J
1648	At N087 15.27 W093 58.XX, turn around
165404	New ALS and Ka-file
	Stop DSLR, download data
171044	New Ka-file
172748	New Ka-file
	IS06F
174806	New Ka-file, ground speed 143kn
	Start DSLR
175913	New Ka-file
1803	Overfly in situ site IS05
1813	IS04D
1816	Restart DSLR
182357	New Ka-file
183558	New Ka-file
1841	Clouds, stop DSLR
1855:	End of line
	Stop ALS and Ka
	Approching YLT
190832	Start logging ALS, Ka, DSLR
	Descending
1912	Runway E-> W
	Stop logging Ka-radar
1917	Builing S-> N
1920	Builing N-> S
1923	Builing E-> W
1917	Builing W-> E
192740	New Ka-file
1931	Runway W-> E
~1933	On ground



DOY 106, April 16, 2017: YLT- CS-37225-MOW-NEp1-IceBridge-YLT

ALS + KAREN:

1307	Taxi
1310	Take-off
131143	Ka-radar test file, OK
1320	New scanner file, looks weird, parabola
	Reboot scanner, all OK
133928	New scanner file
1345	CSNE2A
134522	New Ka-file
135817	New Ka-file
141501	New Ka-file
142406	New Ka-file
143222	New Ka-file, start DSLR
	CSNE2E, start of MOW
1448	EOL
145232	MOW1AJ, New Ka-file
	Headwind 110kn ground-speed
1509	EOL
151109	MOW1BL, New Ka-file
1523	**CS-2 satellite passage time**
1524	EOL
152618	MOW1AG, New Ka-file
	No photos on this line, downloading
1541	EOL
1543	MOW1BM, start DSLR
	Ka-radar frozen, Restart Ka-GUI
1555	Hard switch off radar
1558	Crossing the lines
	Stop DSLR, dowloading
160058	New scanner file
1604	Ka-radar up and running
160610	New Ka-file
1609	Descending ~200m low clouds
161727	New Ka-file
1620	Start DSLR
1624	Ascending to 300m
162932	New Ka-file
	New Ka-file
165309	New Ka-file
1701	Stop DSLR, Download
170325	New Ka-file
171326	New Ka-file
1725	End of line CS2NE1
	Going for the IceBridge, Nares Strait
172607	New Ka-file, start DSLR
173720	New Ka-file
1745	Crossing ice edge, grey ice with finger rafting
1748	Following the ice edge
174950	Crossing ice edge
175201	New Ka-file
1757	Crossing ice edge to open water, or nilas
180843	New Ka-file
1813	Crossing ice edge
1815	Go for landing, Stop Ka-file, DSLR
1819	On ground YLT

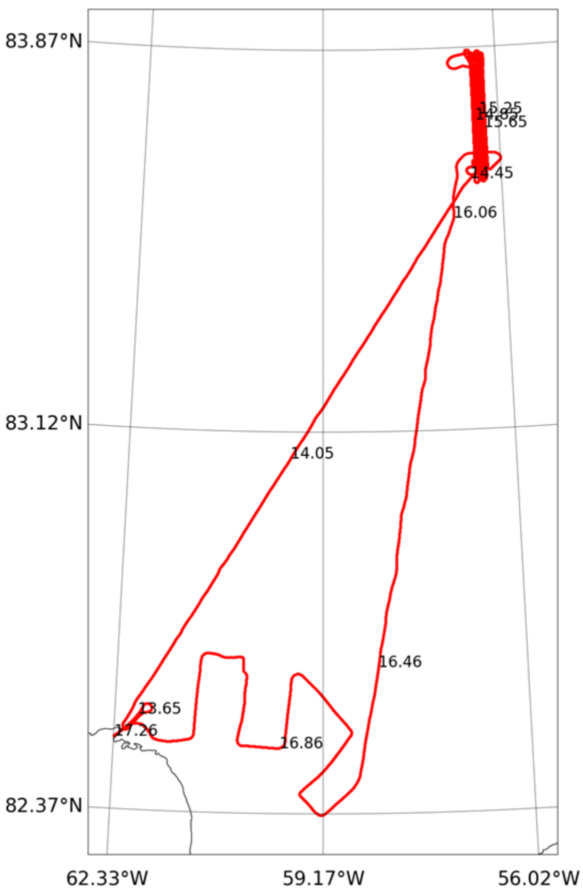


DOY108, April 18, 2017: YLT- ShearZone-IceBridge-YLT

Windy, drifting snow T=-21C

ALS + KAREN:

1330	Re-align EGI, Ka + ALS OK
	Take-off
133735	Ka test-file, OK
	Ka lost connection, no power, Green switch off
134858	New Ka test-file, OK
135016	Start new Ka-file
	EGI froze
1401	Restart EGI-con, EGI OK
140233	All looks OK
	Stop Ka-logging
	96kn ground speed
142524	New Ka-file
1430	At the MOW area
143133	SZ01A, New Ka-file
143930	SZ02B, New Ka-file
	EGI froze again
1443	Restart EGIcon, new EGI file
144404	New Ka-file
1446	End of line
144754	SZ03A, New Ka-file, DSLR
1454	End of line
145629	SZ04B, New Ka-file, DSLR
1502	End of line
150358	SZ05A, New Ka-file, DSLR
1510	End of line
151217	SZ06B, New Ka-file, DSLR
1518	End of line
152022	SZ07A, New Ka-file, DSLR
1527	End of line
152841	SZ08B, New Ka-file, DSLR
1535	End of line
153637	SZ09A, New Ka-file, DSLR
1543	End of line
155020	SZ10B, New Ka-file, DSLR
1556	End of line
	Left turn
155836	Crossing lines, New Ka-file, DSLR
1605	New scanner file
160544	New Ka-file
161519	New Ka-file
162615	New Ka-file
	Icebrige, Crossing ice -> water
163718	New Ka-file
1640	Water -> ice
164346	New Ka-file
1650	Ice -> water
165125	New Ka-file
1655	Water -> ice
170039	New Ka-file
1705	Ice -> water
1707	Water -> ice
170912	New Ka-file
	Inbound for landing
1710	Stop Ka log-file
1713	On ground YLT



DOY 109a, April 19, 2017: YLT- YEU

No survey

ALS + KAREN:

1255	Nav not navrdy
~1257	Take-off
1520	On ground YEU

DOY 109b, April 19, 2017: YEU- YRB

No survey

ALS + KAREN:

1557	INS aligned, OK
1558	Take-off
1655	Main switch off :-(
	Stop INS
1832	On ground YRB

DOY 110, April 20, 2017: YRB –CYGZ, CYGZ-NAQ

ALS + KAREN:

CYGZ Grise Fjord
Survey Hells Gate and Jones Strait
No Ka-radar, backup

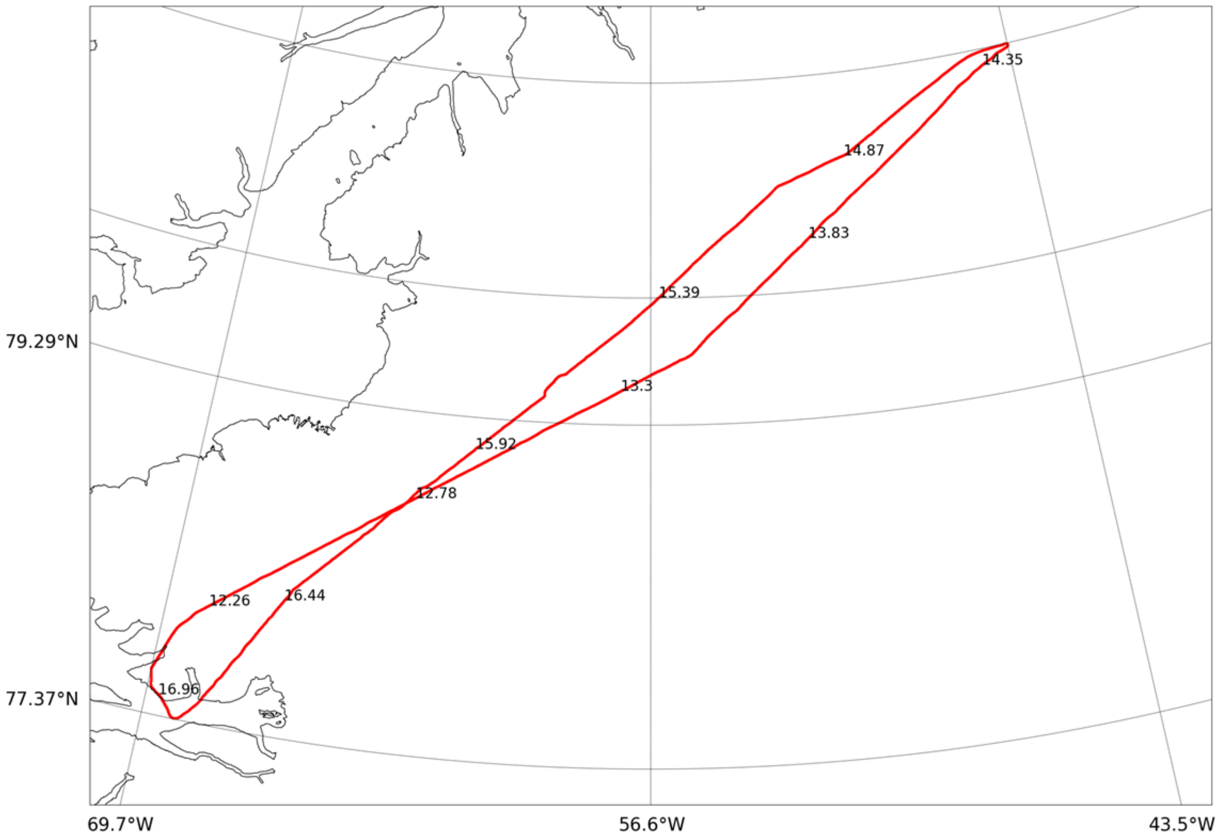
1333	Ready to go
1337	Take-off
143410	Approaching Hells Gate
	New scanner file
1440	Very thin layer of clouds
	ALS signal on and off
	Stop DSLR
1446	Stop survey too many low clouds
145006	New scanner file + DSLR
	~150m altitude, nice signal
1504	Stop DSLR no contrast
1539	Stop survey
1540	On ground CYGZ
1627	Taxi
1631	Take off
1643	Polynya
1645	Low thin clouds
1813	On ground

DOY 111, April 21, 2017: NAQ-A3-H-NAQ

NAQ-STN, had to return to NAQ due to bad weather at STN
No Ka-radar, backup

ALS:

1152	Ready to go
1156	Take-off
	Stop scanner
121751	New scanner file, ~450m a.g.
131930	New scanner file
142102	New scanner file
1425	Return to NAQ
	Shut down ALS
1654	On ground NAQ

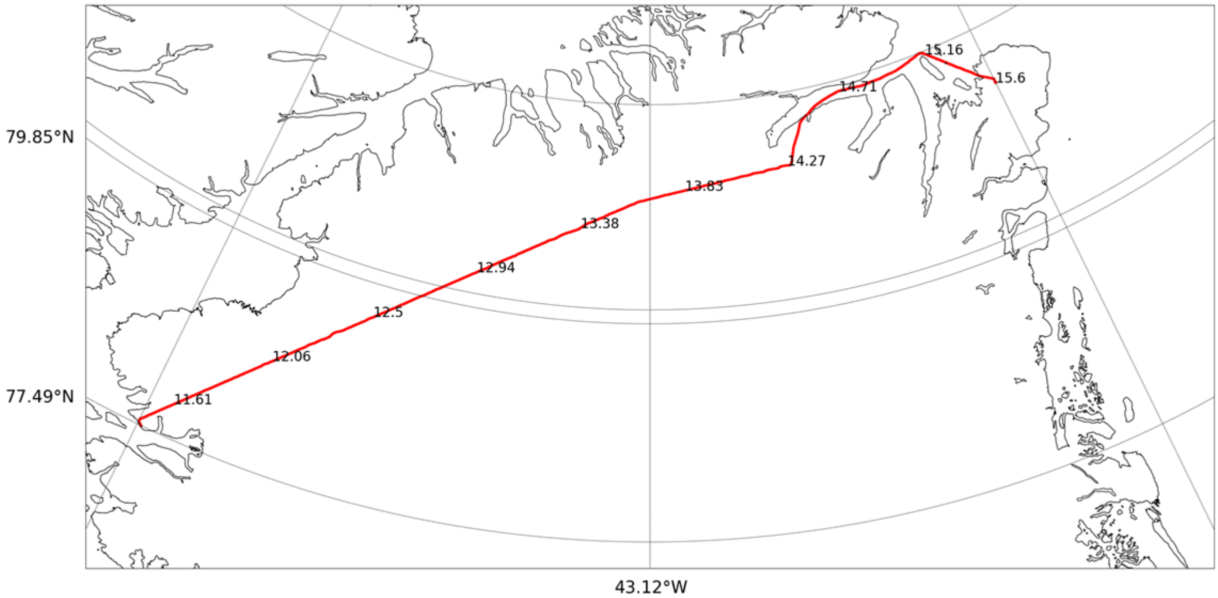


DOY 114a, April 24, 2017: NAQ-H-STN

No Ka-radar, backup

ALS:

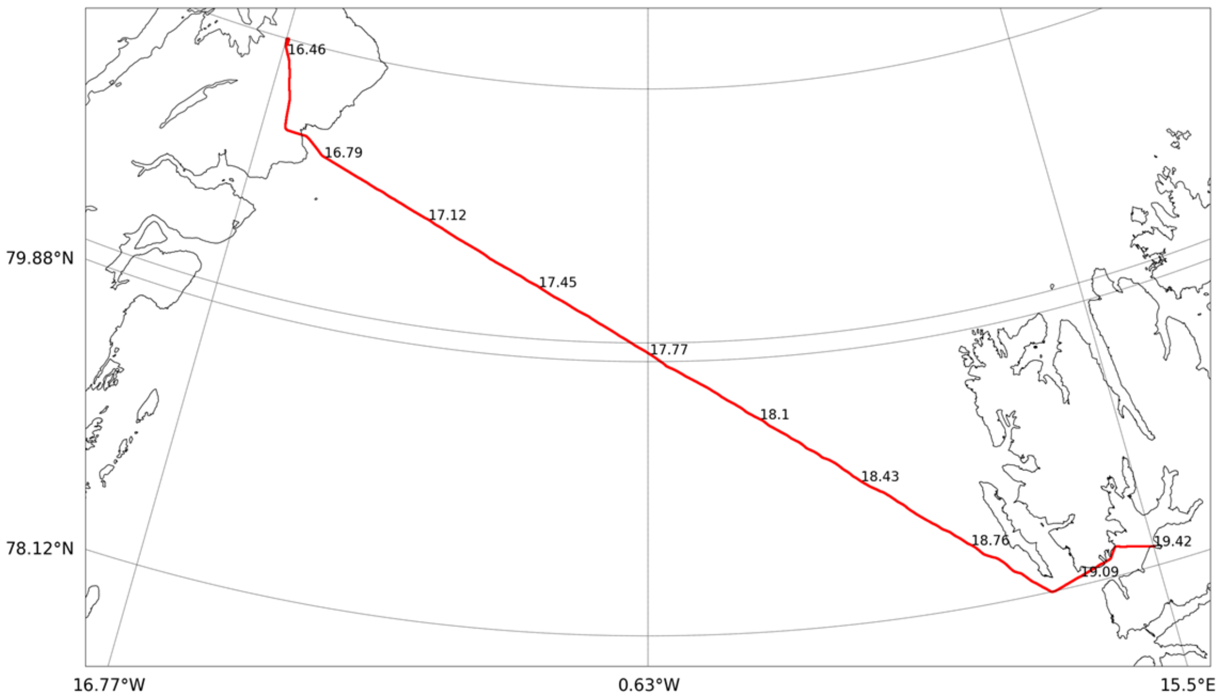
1119	Taxi
1121	Take-off
134007	Start scanner file
	Start survey at ~N81.14, W42.10
1410	Start DSLR
1413	Circumnavigating rock
1420	Very thin layer of clouds, No ALS
1421	Stop DSLR
1428	OK, weather, clear
	A bit off the line, due to clouds
152329	New scanner file
1532	On ground STN



DOY 114b, April 24, 2017: STN-S3-LYR

ALS + KAREN:

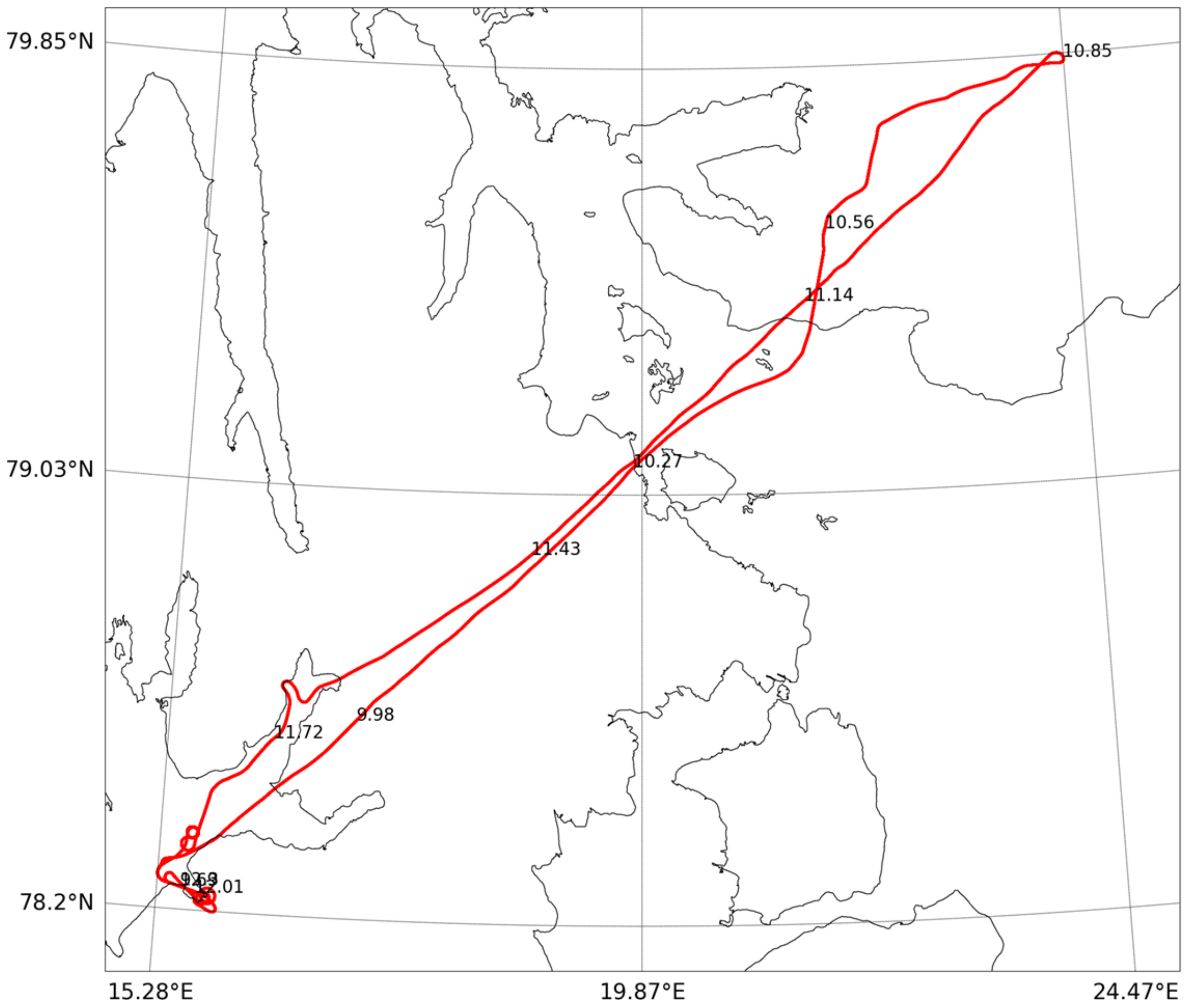
1618	Taxi
1622	Take-off
164014	New scanner file
162937	New Ka-file
	Flade Isblink
163905	New Ka-file
1646	Glacier front
	Start camera
164853	New Ka-file
165836	New Ka-file
170733	New Ka-file, 151 knots
171628	New Ka-file
1724	Scattered clouds
172532	New Ka-file
173444	New Ka-file
173619	New scanner file
174354	New Ka-file
1749	Scattered low clouds/fog
175323	New Ka-file
180224	New Ka-file
1805	ice-edge ?
	Scattered ice floes
~1809	S3 satellite passage time ~N79 24.80 E03 52.00
1812	Open water with snow showers
1812	Open water with snow showers
1814	Persistent snow, stop logging
	Climbing
1921	On ground LYR



DOY 115, April 25, 2017: LYR-Austfonna-LYR

ALS + KAREN:

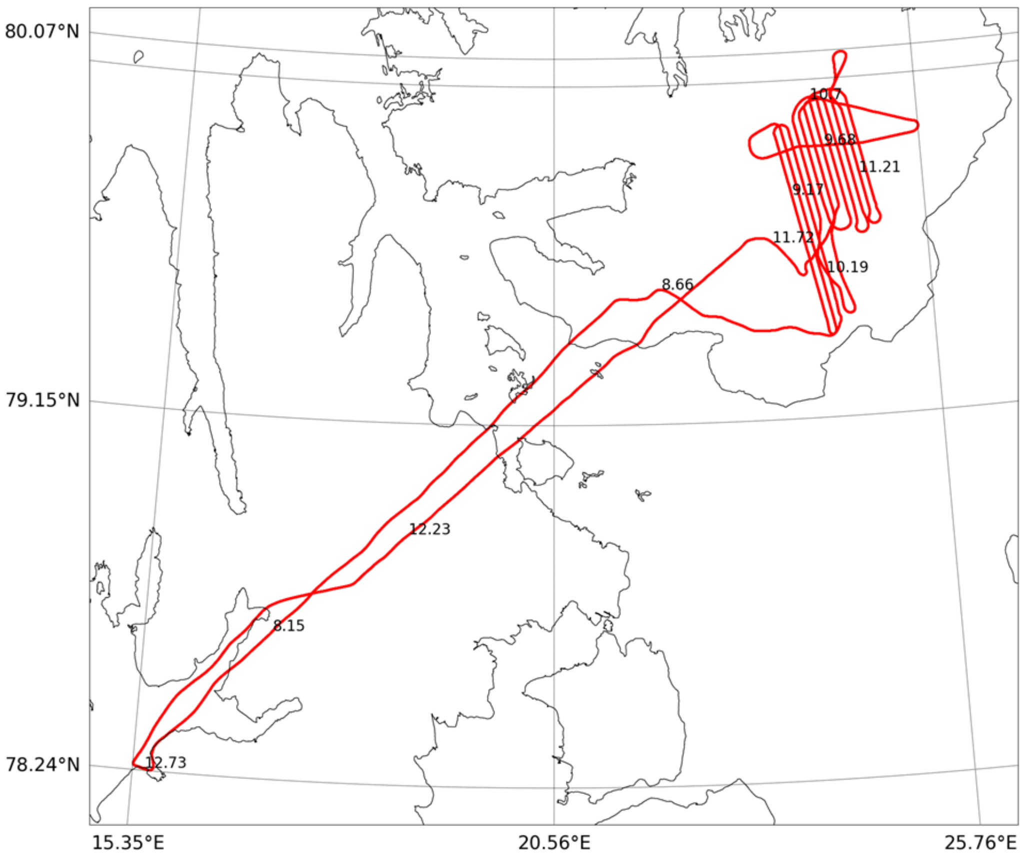
0938	Ready to go
0940	Taxi
0943	Take-off
0945	Scanner stop logging
0946	Ka test-file, OK
1025	Start scanner
1027	L1_1
1028	Start new Ka-file
1032	L1_2
1033	L1_3
1034	L1_4
1036	L1_5
1037	L1_6
1038	Clouds between LI_6 and Eton
1047	Ka start/stop
	Still clouds
1047	SV3
1050	Survey stopped, due to persistent cloud cover
1050	Stop scanner
1053	Ka-radar stopped logging
	Returning to LYR for calibration flight
1149	Scanner started
1156	New Ka-file
1159	Runway overflight
1203	Runway overflight
1205	Ka-radar stop logging
1206	Building E->W
120940	Building S->N
1210	Stop scanner
1214	On ground LYR



DOY 116, April 26, 2017: LYR-Austfonna-LYR

ALS + KAREN:

0751	Taxi
0755	take-off
0813	started Ka
0814	stopped Ka, test-file ok
0825	all systems ok
0839	start scanner
0840	clouds ahead heading for cs-tracks
0847	started ka
0848	clouds, no signal
0849	return from clouds
0853	on line L13s19-L13n19, from now on the line will be referred to as LxxCS19
0858	stop/start Ka
0905	end line L13CS19
0906	start line L21CS19 towards south
0914	stop/start Ka
0918	clouds turn, stop/start scanner
0910	on line L17CS19 towards north
0929	stop/start Ka
0933	go lines Sv2-Sv3
0934	stopped ka
0937	on line sv2-sv3, started Ka
0939	at sv3
0942	at sv4
0946	at sv5 and turn, stoppe dka
0947	clouds
0948	started ka
0950	stop ka
0953	stop/start scanner, clouds
0955	on line CS19n-CS19s
0956	starting ka surface in scn.
1003	stopped ka clouds
1006	on line L5CS19
1007	turned for L9CS19 towards north to avoid clouds, no luck back on line L9CS19
1014	no clouds on L9CS19
1015	Started Ka
1021	turn stopped ka
1024	on R9CS19 towards south, clouds
1025	started Ka no clouds
1031	turn, clouds, ka stop
1034	on line L5CS19 towards north, started Ka
1040	turn, ka stop, clouds
1042	scanner stopped/start
1043	on line R13CS19 towards north, ka started
1049	turn, ka-stop, clouds
1053	on line R17CS19 north ka-start
1059	clouds ka-stop, turn
1108	on line R21CS19 south, ka-start
1114	clouds ka-stop, turn
1117	on line R25CS19 north, ka-started
1124	clouds ka-stop, turn
1128	on line R5CS19 south
1134	clouds ka-stop, turn for the ridge exit
1138	stop/start scanner
1139	start ka
1140	at the ridge from NPI
1144	clouds ka and scanner stop, heading for LYR
1239	on ground LYR.



11 APPENDIX Coordinates of GPS base stations

Date	DOY	Reference	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height (m)
Phase 1					
19-03-2017	79A	STN fixed	Not calculated	Not calculated	Not calculated
19-03-2017	79B	STN fixed	Not calculated	Not calculated	Not calculated
20-03-2017	80A	STN	81° 35’ 46.43742’’	-16° 39’ 25.94093’’	62.453
20-032017	80B	STN	81° 35’ 46.43735’’	-16° 39’ 25.99253’’	62.451
24-03-2017	83	YLT	82° 30’ 43.24847’’	-62° 19’ 47.76181’’	50.198
27-03-2017	86	YLT	82° 30’ 43.24865’’	-62° 19’ 47.76286’’	50.197
31-03-2017	90A	JQA	70° 43’ 58.46009’’	-52° 41’ 47.90436’’	113.695
31-03-2017	90B	JQA	70° 43’ 58.46009’’	-52° 41’ 47.90436’’	113.695
Phase 2					
07-04-2017	97A	YCB	69° 06’ 21.07341’’	-105° 07’ 17.78724’’	-13.005
07-04-2017	97B	YCB	69° 07’ 18.15076’’	-105° 02’ 46.63899’’	-20.070
08-04-2017	98	YCB	69° 06’ 21.07316’’	-105° 07’ 17.78587’’	-12.956
13-04-2017	103	YLT	82° 30’ 41.84928’’	-62° 19’ 50.99325’’	50.828
16-04-2017	106	YLT	82° 30’ 41.84945’’	-62° 19’ 51.00366’’	50.803
18-04-2017	108	YLT	82° 30’ 41.83143’’	-62° 19’ 50.84157’’	50.822
25-04-2017	115	LYR	78° 14’ 45.44436’’	15° 30’ 17.42615’’	54.039
26-04-2017	116	LYR	78° 14’ 45.71767’’	15° 30’ 18.05446’’	52.176

12 APPENDIX Overview of acquired ALS data – phase 1

Date	DOY	File name	Start time (dechr)	Stop time (dechr)	Angles (pitch, roll, heading)	dt (s)
18-03-2017	077	077_155330.2dd	11.8919918	12.58027		
19-03-2017	078	078_090330.2dd	09.2085185	09.37203	Only clouds	-
		078_105700.2dd	10.9498577	11.63403	-1.20 -0.11 0.0	-1
		078_120510.2dd	12.0876682	12.15967	-1.20 -0.11 0.0	-1
		078_133230.2dd	13.5415656	14.22997	No INS	-
20-03-2017	079	079_104800.2dd	Error	Error	-1.00 -0.10 0.0	0
		079_121410.2dd	Error	Error	-1.00 -0.10 0.0	0
		079_132300.2dd	Error	Error	-1.00 -0.10 0.0	0
		079_144700.2dd	Error	Error	-1.00 -0.10 0.0	0
		079_154240.2dd	15.7105326	16.01048	-1.00 -0.10 0.0	-1
		079_164110.2dd	16.6865431	17.37497	-1.00 -0.09 0.0	-1
21-03-2017	080	080_102240.2dd	10.3796138	11.06795	-1.00 -0.09 0.0	-1
		080_112100.2dd	11.3477446	12.03618	-1.00 -0.09 0.0	-1
		080_125540.2dd	12.9270748	13.61569	-1.00 -0.09 0.0	-1
		080_134915.2dd	13.8203001	14.50893	-1.00 -0.09 0.0	-1
		080_153510.2dd	15.5851462	16.27376	On ground ?	-
		080_155630.2dd	15.9412343	16.07175	-1.00 -0.10 0.0	0
		080_160540.2dd	16.3574182	17.04583	-1.00 -0.10 0.0	0
		080_172300.2dd	17.3834262	18.07186	-1.00 -0.11 0.0	0
		080_190300.2dd	19.0495518	19.73801	-1.00 -0.11 0.0	0
		080_200630.2dd	20.1066510	20.79530	-1.00 -0.11 0.0	0
22-03-2017	081	081_142130.2dd	14.3594261	15.04800	No INS	-
		081_164420.2dd	16.7390224	17.29017	No INS	-
		081_171750.2dd	17.2957590	17.80800	No INS	-
24-03-2017	083	083_142400.2dd	14.3996700	15.08799	-1.05 0.14 0.0	0
		083_153510.2dd	15.5851462	16.27376	-1.05 0.14 0.0	0
		083_172400.2dd			-1.05 0.14 0.0	0
		083_183050.2dd			-1.05 0.14 0.0	0
		083_195010.2dd	19.8365341	20.13310	-1.05 0.14 0.0	0
27-03-2017	086	086_132545.2dd	Error	Error	-1.05 0.14 0.0	-1
		086_143230.2dd	14.5424921	15.23087	-1.05 0.14 0.0	-1
		086_154710.2dd	15.7860937	16.47451	-1.05 0.14 0.0	-1
		086_165330.2dd	16.8907950	17.57921	-1.05 0.14 0.0	-1
28-03-2017	087	087_134630.2dd	13.7754655	13.95491	-1.05 0.13 0.0	0
		087_135830.2dd	13.9744724	14.66301	-1.05 0.13 0.0	0
		087_152400.2dd	15.3976734	16.08628	-1.05 0.13 0.0	0
		087_163200.2dd	16.5286776	17.21727	-1.05 0.13 0.0	0
29-03-2017	088	088_132340.2dd	13.3945796	13.40346	-1.05 0.16 0.0	-1
		088_132540.2dd	13.4279495	14.11630	-1.05 0.16 0.0	-1
		088_142210.2dd	14.3688424	15.05745	-1.05 0.16 0.0	-1
		088_155420.2dd	16.6072891	17.29570	-1.05 0.16 0.0	-1
30-03-2017	089	089_114345.2dd	11.7296312	12.41795	-1.05 0.14 0.0	-1
		089_125530.2dd	12.9248778	13.61328	-1.05 0.14 0.0	-1
		089_141040.2dd	Error	Error	-1.05 0.14 0.0	0
		089_151640.2dd	Error	Error	-1.05 0.14 0.0	0
		089_152830.2dd	Error	Error	-1.05 0.14 0.0	0
31-03-2017	090	090_080808.2dd	08.1482923	08.83682	-1.05 0.14 0.0	0
		090_085700.2dd	08.9484718	09.63688	-1.05 0.14 0.0	0
		090_102010.2dd	10.3369528	11.02535	-1.05 0.14 0.0	0
		090_142145.2dd	14.3626368	15.05135	-1.05 0.14 0.0	-1
		090_170150.2dd	17.0295635	17.30310	-1.05 0.14 0.0	-1

01-04-2017	091	091_102145.2dd 091_114120.2dd	10.3628259 11.6892823	11.05126 12.37772	-1.05 0.18 0.0 -1.05 0.18 0.0	-1 -1

13 APPENDIX Overview of acquired ALS data – phase 2

Date	DOY	File name	Start (dechr)	Stop (dechr)	Angles (pitch, roll, heading)	dt (s)
05-04-2017	95	170405_212827_Scanner 1.2dd	00.06879	02.84661	See Table 12 Section 5.3.4	499
07-04-2017	97A	170407_191316_Scanner 1.2dd	00.07477	00.78648	0.32 -0.455 0.10	-17
07-04-2017	97B	170407_234446_Scanner 1.2dd	00.09315	02.68990	0.32 -0.455 0.10	512
08-04-2017	98	170408_232213_Scanner 1.2dd 170408_235331_Scanner 1.2dd	00.03683 00.21200	00.19456 02.34060	0.32 -0.46 0.10 0.32 -0.46 0.10	-17 -17
11-04-2017	101	170411_152932_Scanner 1.2dd	00.04209	02.44689	0.32 -0.46 0.10	-17
12-04-2017	102A	170412_145448_Scanner 1.2dd	00.71330	01.74579	0.32 -0.47 0.10	-18
13-04-2017	103	170413_141105_Scanner 1.2dd 170413_141120_Scanner 1.2dd 170413_144740_Scanner 1.2dd 170413_171108_Scanner 1.2dd 170413_191824_Scanner 1.2dd			 0.32 -0.46 0.10 0.32 -0.455 0.10 0.32 -0.455 0.10 0.32 -0.455 0.10	- 2 2 2 2
16-04-2017	106	170416_130714_Scanner 1.2dd 170416_132011_Scanner 1.2dd 170416_133714_Scanner 1.2dd 170416_133928_Scanner 1.2dd 170416_160058_Scanner 1.2dd	13.12060 13.33662 - 00.03333 02.36568	13.30134 13.59839 - 02.36138 04.67762	 0.32 -0.47 0.10 0.32 -0.47 0.10	- - - -17 -17
18-04-2017	108	170418_134643_Scanner 1.2dd 170418_160456_Scanner 1.2dd	13.43293 16.08239	16.07767 17.22149	0.32 -0.47 0.10/ 0.18 -0.15 0.40* 0.32 -0.47 0.10	-17 -17

20-04-2017	110B	170420_134213_Scanner 1.2dd	-	-	No data	-
		170420_135410_Scanner 1.2dd	13.55659	13.69766	?	-
		170420_143410_Scanner 1.2dd	14.56929	14.78102	0.32 -0.47 0.10	-16
		170420_144957_Scanner 1.2dd	-	-	No data	-
		170420_145006_Scanner 1.2dd	14.83492	15.65192	0.32 -0.47 0.10	-16
		170420_164626_Scanner 1.2dd	16.42812	18.23716	0.32 -0.46 0.10	-16
21-04-2017	111	170421_115206_Scanner 1.2dd	00.03333	00.25262	0.32 -0.46 0.10	-17
		170421_121752_Scanner 1.2dd	00.43075	01.45452	0.32 -0.46 0.10	-17
		170421_131930_Scanner 1.2dd	01.45776	02.48028	0.32 -0.46 0.10	-17
		170421_142102_Scanner 1.2dd	02.48334	02.60797	0.32 -0.46 0.10	-17
24-04-2017	114	170424_113834_Scanner 1.2dd	Error	Error	0.32 -0.47 0.10	-17
		170424_114841_Scanner 1.2dd	Error	Error	0.32 -0.47 0.10	-17
		170424_133019_Scanner 1.2dd	Error	Error	0.32 -0.47 0.10	-17
		170424_134007_Scanner 1.2dd	Error	Error	0.32 -0.47 0.10	-17
		170424_152329_Scanner 1.2dd	Error	Error	0.32 -0.47 0.10	-17
		170424_164014_Scanner 1.2dd	16.3257101	17.01641	0.32 -0.46 0.10	-18
		170424_173619_Scanner 1.2dd	17.6057111	18.26381	0.32 -0.46 0.10	-18
25-04-2017	115	170425_093204_Scanner 1.2dd	9.5292661	9.75131	0.32 -0.43 0.10	2
		170425_102530_Scanner 1.2dd	10.4197904	10.85457	0.32 -0.43 0.10	2
		170425_114959_Scanner 1.2dd	11.8278280	12.17468	0.32 -0.43 0.10	2

26-04-2017	116	170426_074829_Scanner 1.2dd	00.0333394	00.03635	0.32 -0.43 0.10	(-17)
		170426_083840_Scanner 1.2dd	00.8488519	01.51910	0.32 -0.43 0.10	-17
		170426_091859_Scanner 1.2dd	01.5209211	02.10651	0.32 -0.43 0.10	-17
		170426_095414_Scanner 1.2dd	02.1084183	02.79911	0.32 -0.43 0.10	-17
		170426_104208_Scanner 1.2dd	02.9066552	03.59734	0.32 -0.43 0.10	-17
		170426_113909_Scanner 1.2dd	03.8569284	03.95776	0.32 -0.43 0.10	-17

14 APPENDIX Overview of acquired ASIRAS data – phase 1

Date	File name	Start time (UTC)	End time (UTC)	Range window (m)	# Pulses
18-03-2017	A170318_00.log	16:13:52	16:17:51	90.00	597496
19-03-2017	A170319_00.log	09:11:11	09:12:15	90.00	159999
	A170319_01.log	11:10:01	11:29:51	90.00	2974981
	A170319_02.log	13:35:07	14:51:01	90.00	11384931
	A170319_03.log	15:08:12	15:23:34	90.00	2304987
20-03-2017	A170320_00.log	11:11:35	14:43:07	90.00	31729805
	A170320_01.log	17:06:11	17:40:33	90.00	5154968
21-03-2017	A170321_00.log	10:30:56	14:56:31	90.00	39837237
	A170321_01.log	16:05:29	20:38:21	90.00	40929730
22-03-2017	A170322_00.log	14:39:55	17:18:11	90.00	23739846
24-03-2017	A170324_00.log	14:28:20	19:45:16	90.00	47539698
27-03-2017	A170327_00.log	13:59:00	18:17:41	90.00	38802243
28-03-2017	A170328_00.log	13:58:37	14:46:25	90.00	7169956
	A170328_01.log	15:17:57	17:18:42	90.00	18112378
29-03-2017	A170329_00.log	13:25:51	14:34:31	90.00	10299935
	A170329_01.log	14:38:32	14:42:21	90.00	572496
	A170329_02.log	14:48:31	14:51:38	90.00	467497
	A170329_03.log	14:52:10	15:23:53	90.00	4757470
	A170329_04.log	15:30:52	16:17:46	90.00	7034954
	A170329_05.log	16:19:32	17:50:59	90.00	13717411
30-03-2017	A170330_00.log	11:58:10	12:07:28	90.00	1394992
	A170330_01.log	12:22:45	15:27:41	90.00	27739818
	A170330_02.log	15:54:49	15:59:49	90.00	749995
31-03-2017	A170331_00.log	09:00:44	11:03:29	90.00	18412378
	A170331_01.log	14:35:46	15:55:42	90.00	11989921
	A170331_02.log	17:01:32	17:09:22	90.00	1174993
01-04-2017	A170401_00.log	10:32:44	12:28:20	90.00	17339891

15 APPENDIX Overview of acquired data from Ka-band radar

Acquisition overview of the 19th of March 2017 flight.

#	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
112530	400	8.2	~1	Calibration track over Constable Point
112759			~1	
112909			~1	
134212			10	B1B2
135321			20	B1B2
141405			9	B1B2
143306			5	B2B3
151230			5	
151808			5	

Acquisition overview of the 21st of March 2017, morning flight.

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
104909	600	6.15	20	Track C9C5
111213			30	Track C9C5
114322				Track C9C5_2
114653			30	Track C5C1
121804			20	Track C5C1
124024				Track C5C1_2
130345				Track C1C5
131054			20	
133415			10	
135109			10	
140904			20	
143027			20	
145222			5	

Acquisition overview of the 21st of March 2017, afternoon flight.

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
160835	600	6.15	20	Track STN-F1
163008			30	
171329			30	Track F1-F2
174729			30	
182000			40	

190504				Track F2-STN
191725			30	
195101			30	
202358			9	

Acquisition overview of the 22nd of March 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
145001	400	8.2	8	Track H1H2
145841			11	Track H2H3
151119			10	Track H3H4
152229			11	Track H4H5
153426			9	Track H5H6
154942			20	Track H6H7
161058			18	
163117			30	Track H7C32
171105			7	Track C32C33

Acquisition overview of the 24th of March 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
145351	600	6.15	30	Track 1A-36892N
152401			18	Track 1A-36892N
154228			30	Track 36892N-Q
161252			15	Track 36892N-Q
162806			30	Track 36892Q-U
165817				Track 36892Q-U
173154			30	Track 36892U-Q
181335				Track 36892U-Q
182152			20	Track 36892Q-N
184142			17	Track 36892Q-N
191431			20	Track 36892N-1A

Acquisition overview of the 27th of March 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
140415	600	6.15		Track YLT-1
143543			2	Track 1-3_4
143815			10	Track 3-6
144827			12	Track 3-6_2
150206			10	Track 3-6_3
151309			5	Track 3-6_4
151759			20	Track 6-8
151819			7	Track 6-8_2
155115			20	Track 8-64
161227			20	Track 8-64_2
163256			3	Track 8-64_3
164023			20	Track 46-62
170103			6	Track 46-62_2
171944			10	Track 62-78_3
173056			2	Track 62-78_4
173415			13	Track 78-102
174719			4	Track 78-102 _2
175347				Track 78-102 _3

Acquisition overview of the 28th of March 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
140606	600	6.15	Cal	Calibration track over airport runway (NS)
141101			Cal	Calibration track over airport runway (SN)
141905			18	Track C20-C19
143851			8	Track C19-C18
151939			20	TrackA4-A3
154034			10	TrackA4-A3_2
155656			30	Track A3-NW7
163213			25	Track A3-NW7_2
165738			5	Track A3-NW7_3

Acquisition overview of the 29th of March 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
134011	400	6.15	20	Track TAB-450_part1
140321			20	Track TAB-450_part2
150319			11	Track 450_2-450_9
153248			1	Track May3_9- May3_1
153313			20	Track May3_9- May3_1
161324			3	Track 174802-22
162314	600		20	Track 174802-22
164321			34	Track 174802-22
172046			30	Track 174802-22

Acquisition overview of the 30th of March 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
122050	400	6.15	12	TrackTAB-D1
123918			10	TrackTAB-D1
125522			14	TrackTAB-D1
132031			10	TrackTAB-D1
133954			10	TrackTAB-D1
141029			10	TrackTAB-D1
144041			15	TrackTAB-D1
150752			5	TrackTAB-D1

Acquisition overview of the 31st of March 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
090724	500	6.15	34	TrackA01A03
094203			30	TrackA03A05
101430			32	TrackA05A07
104651			5	TrackA07A08
105715			5	TrackA08 A07
145125			6	T3T5
145709			10	T5T9
150716				T9T12 over twin otter
152259				Over twin otter
153253				Over twin otter
153622			17	T12T19
170431				Over airport runway
1170801				Over airport runway
1171220				Over hotel

Acquisition overview of the 1st of April 2017

Acq #	Bw [MHz]	PRF [KHz]	Duration [mins]	Notes
104255	500	6.15	5	trackT19-T21, begin 210.avi
104842			23	trackT21-T41
111133				trackT21-T41 over twin otter
111805				Perpendicular to trackT21-T41 over twin otter
112643				trackT21-T41 over twin otter
112820			22	trackT21-T41
115213			3	trackT41-EG5
115519			20	
121549			12	trackEG5-EG6

Acquisition overview for the 5th of April 2017.

Acq #	Dimension [Gb]	Notes
20170405213754	66	YCB- ALtiKa-YCB
20170405215525	70	
20170405221401	74	
20170405223027	70	
20170405224942	70	
20170405230626	68	
20170405232313	68	
20170405233742	5	

Acquisition overview for the 7th of April 2017.

Acq #	Dimension [Gb]	Notes
20170407153927	5	Test
20170407192535	44	YCB-TER-YCB, flight cancelled due to low clouds
20170407233847	60	
20170407235208	21	
20170407235907	51	
20170408001959	57.4	
20170408003214	43.3	
20170408005230	46.5	
20170408010606	45.5	
20170408011522	42.8	
20170408012501	43.3	
20170408013345	51	
20170408014359	51.8	
20170408015441	10.8	

Acquisition overview for the 8th of April 2017.

Acq #	Dimension [Gb]	Notes
20170408230000		
20170409000242	50.1	
20170409001426	48.9	
20170409002539	15.1	
20170409003055	23.3	
20170409003725	15.3	
20170409004226	23.5	
20170409004933	15.1	
20170409005356	23.6	
20170409010020	14	
20170409010432	21.7	

20170409011044	12.1	
20170409011502	19.7	
20170409012017	10.4	
20170409012403	36.8	
20170409013235	48.2	

Acquisition overview for the 11th of April 2017.

Acq #	Dimension [Gb]	Notes
20170411163647	92	YCB-McClintock-YRB
20170411165356	10	
20170411171327	10	
20170411173326	15.3	

Acquisition overview for the 12h of April 2017.

Acq #	Dimension [Gb]	Notes
20170412151015	88	YRB- C1-C2-C3-YEU
20170412152600	73	
20170412153937	93	

Acquisition overview for the 13th of April 2017.

Acq #	Dimension [Gb]	Notes
20170413140145	81	YLT- InSitu-YLT
20170413142703	59	
20170413143800	60	
20170413144901	53	
20170413145841	53	
20170413150842	55	
20170413151836	84	
20170413153342	80	
20170413154804	82	
20170413160957	107	
20170413162910	105	
20170413165404	93	

Acquisition overview for the 18th of April 2017.

Acq #	Dimension [Gb]	Notes
20170418135016	68	YLT- ShearZone-IceBridge-YLT
20170418140233	56	
20170418142524	17	
20170418143133	35	
20170418143930	24	
20170418144404	12	
20170418144754	32	
20170418145629	33	
20170418150358	40	
20170418151217	37	
20170418152022	36	
20170418152841	35	
20170418153637	37	
20170418155020	34	
20170418155836	39	
20170418160544	52	
20170418161519	60	
20170418162615	53	

Acquisition overview for the 24th of April 2017.

Acq #	Dimension [Gb]	Notes
20170424162937	52	STN-S3-LYR
20170424163905	50	
20170424164853	52	
20170424165836	49	
20170424170733	49	
20170424171628	50	
20170424172532	51	
20170424173444	51	
20170424174354	52	
20170424175323	50	
20170424180224	66	

Acquisition overview for the 25th of April 2017.

Acq #	Dimension [Gb]	Notes
20170425102823	107	LYR-Austfonna-LYR
20170425104737	30	
20170425115655	46	

Acquisition overview for the 26th of April 2017.

Acq #	Dimension [Gb]	Notes
		LYR-Austfonna-LYR
20170426084726	60	
20170426085816	90	
20170426091418	86	
20170426092950	28	
20170426093726	51	
20170426094902	10	
20170426095610	40	
20170426101543	32	
20170426102514	34	
20170426103445	33	
20170426104339	33	
20170426105358	33	
20170426110852	35	
20170426111743	41	
20170426112852	34	
20170426113928	29	

16 APPENDIX File name convention

In general, the filename contains a shortcut for the instrument and the start and stop time of the data file.

KAREN:
KAR_OPER_Level1b_ SSSSSSSSSSSSSSS_ PPPPPPPPPPPPPPP_XXXX.nc

SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPPPPPPPPPPP	Stop time given as YYYYMMDDTHHMMSS
XXXX	version of processing, as described in Section 5.5.1, thus XXXX could e.g. be “hamh”

ASIRAS:
AS30AXX_ASIWL1BNNNN_SSSSSSSSSSSSSSS_PPPPPPPPPPPPPPP_0001.DBL

AS30AXX	ASIRAS (AS30), AXX number of data log
ASIWL1BNNNN	Level 1B data (L1B) processor version (NNNN)
SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPPPPPPPPPPP	Stop time given as YYYYMMDDTHHMMSS

GPS
GPS_ANT_VER_SSSSSSSSSSSSSSS-PPPPPP_0001.DBL

ANT	GPS antenna, e.g. R for rear, and F for front
VER	Version
SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS

Inertial Navigation System (INS)
INS_ SSSSSSSSSSSSSSS-PPPPPP_0001.DBL

SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS

Airborne laser scanner (ALS) full resolution
ALS_SSSSSSSSSSSSSSS-PPPPPP.nc

SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS

17 APPENDIX Processed GPS data in ESA format

Differentially processed GPS data is delivered in binary, big endian format with each record formatted as described by Cullen (2010).

Date	DOY	File	Size [MB]
19-03-2017	78	GPS_R_20170319T085742_153614_0001.DBL	1.4
20-03-2017	79	GPS_R_20170320T104217_161214_0001.DBL	1.2
20-03-2017	79	GPS_R_20170320T163612_184154_0001.DBL	0.5
21-03-2017	80	GPS_R_20170321T102743_152438_0001.DBL	1.1
21-03-2017	80	GPS_R_20170321T155654_211134_0001.DBL	1.1
24-03-2017	83	GPS_R_20170324T141322_201658_0001.DBL	1.3
27-03-2017	86	GPS_R_20170327T132621_183802_0001.DBL	1.1
28-03-2017	87	GPS_R_20170328T133620_175559_0001.DBL	0.9
29-03-2017	88	GPS_R_20170329T131653_183826_0001.DBL	1.2
30-03-2017	89	GPS_R_20170330T112116_162143_0001.DBL	2.2
31-03-2017	90	GPS_R_20170331T074707_130849_0001.DBL	1.2
31-03-2017	90	GPS_R_20170331T134206_172142_0001.DBL	0.8
01-04-2017	91	GPS_R_20170401T091537_123202_0001.DBL	0.7

Date	DOY	File	Size [MB]
05-04-2017	95		
07-04-2017	97	GPS_BAS_20170407T184537_195448_0001.DBL	0.2
07-04-2017	97	GPS_BAS_20170407T231855_260758_0001.DBL	0.6
08-04-2017	98	GPS_BAS_20170408T232349_254848_0001.DBL	0.5
11-04-2017	101	GPS_BAS_20170411T152209_194447_0001.DBL	1.0
12-04-2017	102	GPS_BAS_20170412T133637_170330_0001.DBL	0.7
12-04-2017	102	GPS_BAS_20170412T174807_201027_0001.DBL	0.5
13-04-2017	103	GPS_BAS_20170413T134722_193915_0001.DBL	1.3
16-04-2017	106	GPS_BAS_20170416T125227_182215_0001.DBL	1.2
18-04-2017	108	GPS_BAS_20170418T131501_171553_0001.DBL	0.9
19-04-2017	109	GPS_BAS_20170419T125717_152257_0001.DBL	0.5
20-04-2017	110	GPS_BAS_20170420T132537_154338_0001.DBL	0.5
20-04-2017	110	GPS_BAS_20170420T162010_181646_0001.DBL	0.4
21-04-2017	111	GPS_BAS_20170421T114432_165810_0001.DBL	1.1
24-04-2017	114	GPS_BAS_20170424T111031_153612_0001.DBL	1.0
24-04-2017	114	GPS_BAS_20170424T160813_192516_0001.DBL	0.
25-04-2017	115	GPS_BAS_20170425T092431_120837_0001.DBL	0.6
26-04-2017	116	GPS_BAS_20170426T073852_124425_0001.DBL	1.1

18 APPENDIX Processed INS data in ESA format

Processed INS data is delivered in binary, big endian format with each record formatted as described by Cullen (2010).

Date	DOY	File	Size [MB]
19-03-2017	78	INS_20170319T110036_125554_0001.DBL	11.9
20-03-2017	79	INS_20170320T085651_161136_0001.DBL	44.9
20-03-2017	79	INS_20170320T163638_184334_0001.DBL	13.1
21-03-2017	80	INS_20170321T100834_155043_0001.DBL	35.3
21-03-2017	80	INS_20170321T155108_210919_0001.DBL	32.8
24-03-2017	83	INS_20170324T141312_201725_0001.DBL	37.6
27-03-2017	86	INS_20170327T132548_183730_0001.DBL	32.2
28-03-2017	87	INS_20170328T133600_175608_0001.DBL	26.9
28-03-2017	87	INS_20170328T133636_175608_0001.DBL	26.8
29-03-2017	88	INS_20170329T131648_183900_0001.DBL	33.2
30-03-2017	89	INS_20170330T112100_162119_0001.DBL	31.0
31-03-2017	90	INS_20170331T074648_130846_0001.DBL	33.2
31-03-2017	90	INS_20170331T135157_172147_0001.DBL	21.7
01-04-2017	91	INS_20170401T091536_123225_0001.DBL	20.3

Date	DOY	File	Size [MB]
05-04-2017	95		
07-04-2017	97	INS_20170407T184839_195333_0001.DBL	6.7
07-04-2017	97	INS_20170407T232053_260712_0001.DBL	17.2
08-04-2017	98	INS_20170408T232324_254745_0001.DBL	14.9
11-04-2017	101	INS_20170411T152534_194314_0001.DBL	26.6
12-04-2017	102	INS_20170412T134800_170234_0001.DBL	20.1
12-04-2017	102	INS_20170412T180051_200951_0001.DBL	13.3
13-04-2017	103	INS_20170413T134648_193738_0001.DBL	36.2
16-04-2017	106	INS_20170416T130600_182107_0001.DBL	32.5
18-04-2017	108	INS_20170418T132821_134646_0001.DBL	1.9
18-04-2017	108	INS_20170418T140046_143906_0001.DBL	4.0
18-04-2017	108	INS_20170418T144221_171437_0001.DBL	15.7
18-04-2017	108	INS_OXTS_20170418T131454_171546_0001.DBL	124.3
19-04-2017	109	INS_20170419T124333_152219_0001.DBL	16.4
20-04-2017	110	INS_20170420T132727_154224_0001.DBL	13.9
20-04-2017	110	INS_20170420T163122_181549_0001.DBL	10.8
21-04-2017	111	INS_20170421T114614_165727_0001.DBL	32.1
24-04-2017	114	INS_20170424T111350_153502_0001.DBL	27.0
24-04-2017	114	INS_20170424T162136_192404_0001.DBL	18.8
25-04-2017	115	INS_20170425T093824_121733_0001.DBL	16.4
26-04-2017	116	INS_20170426T075024_124306_0001.DBL	30.2

19 APPENDIX Processed ALS data

Date	DOY	File	Size [MB]
19-03-2017	78	ALS_20170319T110602_113659.nc	45.6
20-03-2017	79	ALS_20170320T105545_121334.nc	307.2
		ALS_20170320T121409_132218.nc	287.1
		ALS_20170320T132233_144633.nc	365.3
		ALS_20170320T144700_150838.nc	78.1
		ALS_20170320T154236_160036.nc	83.3
		ALS_20170320T164537_174444.nc	266.9
21-03-2017	80	ALS_20170321T102554_112024.nc	253.4
		ALS_20170321T112050_125511.nc	437.7
		ALS_20170321T125536_134736.nc	252.6
		ALS_20170321T134912_151212.nc	400.4
		ALS_20170321T160048_160418.nc	3.9
		ALS_20170321T162126_172234.nc	289.7
		ALS_20170321T172300_190209.nc	489.5
		ALS_20170321T190258_200602.nc	304.2
		ALS_20170321T200623_210631.nc	289.5
24-03-2017	83	ALS_20170324T142358_153442.nc	316.7
		ALS_20170324T153506_164704.nc	346.5
		ALS_20170324T164745_172338.nc	175.6
		ALS_20170324T172401_183019.nc	328.7
		ALS_20170324T183043_194947.nc	386.1
		ALS_20170324T195011_200759.nc	67.5
27-03-2017	86	ALS_20170327T135357_142809.nc	164.3
		ALS_20170327T143231_154640.nc	358.1
		ALS_20170327T154708_165307.nc	298.3
		ALS_20170327T165325_183321.nc	473.8
28-03-2017	87	ALS_20170328T135614_135717.nc	1.2
		ALS_20170328T135828_152332.nc	155.6
		ALS_20170328T152351_163118.nc	273.8
		ALS_20170328T163143_172233.nc	199.1
29-03-2017	88	ALS_20170329T132339_132411.nc	0.5
		ALS_20170329T132539_142148.nc	218.8
		ALS_20170329T142206_155400.nc	271.8
		ALS_20170329T163625_175559.nc	327.2
30-03-2017	89	ALS_20170330T114441_115617.nc	27.7
		ALS_20170330T125528_132930.nc	119.1
		ALS_20170330T141040_151600.nc	259.2
		ALS_20170330T151635_152433.nc	21.5
		ALS_20170330T155216_155957.nc	20.3
31-03-2017	90	ALS_20170331T080853_085616.nc	171.2
		ALS_20170331T085654_101949.nc	197.7
		ALS_20170331T102013_110651.nc	194.3

		ALS_20170331T143356_155502.nc	305.5
		ALS_20170331T170145_171810.nc	71.1
01-04-2017	91	ALS_20170401T102145_114056.nc	288.2
		ALS_20170401T114120_123148.nc	175.7

Date	DOY	Final file:	File size (MB)
05-04-2017	95		
07-04-2017	97	**ALS_20170407T192157_193253.sbi**	
		ALS_20170407T233303_255931.sbi	
08-04-2017	98	**ALS_20170408T233055_233124.sbi**	
		ALS_20170408T233227_254010.sbi	
11-04-2017	101	**ALS_20170411T163311_175332.sbi**	
12-04-2017	102	ALS_20170412T145430_155627.nc	307.2
13-04-2017	103	ALS_20170413T135740_141622.nc	83.1
		ALS_20170413T142643_164904.nc	785.1
		ALS_20170413T170000_185616.nc	635.7
		ALS_20170413T190000_193459.nc	122.0
16-04-2017	106	ALS_20170416T133911_160025.nc	764.8
		ALS_20170416T160041_174304.nc	585.1
18-04-2017	108	ALS_20170418T133056_134645.nc	48.2
		ALS_20170418T134646_140047.nc	74.6
		ALS_20170418T140047_143906.nc	225.4
		ALS_20170418T143906_144221.nc	18.6
		ALS_20170418T144221_160422.nc	470.1
		ALS_20170418T160439_163458.nc	172.0
20-04-2017	110	ALS_20170420T143616_144540.nc	13.1
		ALS_20170420T144949_151312.nc	112.0
		ALS_20170420T151528_153850.nc	117.8
		ALS_20170420T163154_181326.nc	373.0
21-04-2017	111	ALS_20170421T115653_120306.nc	18.8
		ALS_20170421T121735_131901.nc	195.5
		ALS_20170421T131912_142033.nc	186.4
		ALS_20170421T142045_142813.nc	28.3
24-04-2017	114	ALS_20170424T112125_112757.nc	32.5
		ALS_20170424T134017_152255.nc	490.8
		ALS_20170424T152312_153109.nc	45.6
		ALS_20170424T162307_173551.nc	338.2
		ALS_20170424T173602_181531.nc	166.9
25-04-2017	115	ALS_20170425T102513_103747.nc	49.0
		ALS_20170425T114942_121030.nc	38.6
26-04-2017	116	ALS_20170426T083822_091809.nc	167.2
		ALS_20170426T092036_094932.nc	119.5
		ALS_20170426T095506_104042.nc	149.2
		ALS_20170426T104300_113434.nc	179.1

20 APPENDIX Time-tagged and geo-located images

ASCII file	Date	File name of zipped file	File Size (MB)
PIX_slant_20170320.pos	20-03-2017	PIX_slant_20170320T130929-135959.zip	720.5
		PIX_slant_20170320T140011-142733.zip	427.9
PIX_slant_20170320B.pos	20-03-2017	PIX_slant_20170320T171518-174142.zip	426.8
PIX_slant_20170321A.pos	21-03-2017	PIX_slant_20170321T105059-105959.zip	77.5
		PIX_slant_20170321T110011-115955.zip	424.9
		PIX_slant_20170321T120007-125957.zip	256.2
		PIX_slant_20170321T130007-135955.zip	33.4
		PIX_slant_20170321T140007-145527.zip	406.3
PIX_slant_20170321B.pos	21-03-2017	PIX_slant_20170321T161211-165949.zip	299.1
		PIX_slant_20170321T170001-175517.zip	218.2
		PIX_slant_20170321T180931-185953.zip	112.2
		PIX_slant_20170321T190005-194903.zip	100.1
PIX_slant_20170322.pos	22-03-2017	PIX_slant_20170322T145854-145954.zip	6.0
		PIX_slant_20170322T150006-155950.zip	166.0
		PIX_slant_20170322T160002-165952.zip	44.9
		PIX_slant_20170322T170004-175322.zip	127.4
PIX_slant_20170324.pos	24-03-2017	PIX_slant_20170324T143732-145956.zip	147.8
		PIX_slant_20170324T150008-155950.zip	313.0
		PIX_slant_20170324T160002-165956.zip	326.5
		PIX_slant_20170324T170008-175948.zip	224.4
		PIX_slant_20170324T180000-185956.zip	249.8
		PIX_slant_20170324T190008-195954.zip	344.8
		PIX_slant_20170324T200006-201314.zip	41.6
PIX_slant_20170327.pos	27-03-2017	PIX_slant_20170327T140933-145950.zip	101.3
		PIX_slant_20170327T150002-155950.zip	96.4
		PIX_slant_20170327T160002-165454.zip	159.1
		PIX_slant_20170327T170006-174926.zip	106.1
PIX_slant_20170328.pos	28-03-2017	PIX_slant_20170328T141522-145958.zip	77.4
		PIX_slant_20170328T150008-155956.zip	57.3
		PIX_slant_20170328T160006-165958.zip	133.1
		PIX_slant_20170328T170008-173342.zip	96.5
PIX_slant_20170329.pos	29-03-2017	PIX_slant_20170329T133513-135955.zip	76.6
		PIX_slant_20170329T140007-145951.zip	127.5
		PIX_slant_20170329T150003-150413.zip	13.4
		PIX_slant_20170329T161845-165951.zip	147.2
		PIX_slant_20170329T170003-175719.zip	153.3
PIX_slant_20170330.pos	30-03-2017	PIX_slant_20170330T120104-125956.zip	183.9
		PIX_slant_20170330T130008-135956.zip	157.1
		PIX_slant_20170330T140008-145954.zip	154.7
		PIX_slant_20170330T150006-155956.zip	135.4
		PIX_slant_20170330T160008-160740.zip	17.2
PIX_slant_20170331.pos	31-03-2017	PIX_slant_20170331T090820-095952.zip	61.6
		PIX_slant_20170331T100004-105956.zip	172.0
		PIX_slant_20170331T110008-110826.zip	22.4

ASCII file	Date	File name of zipped file	File Size (MB)
	05-04-2017		
PIX_BAS_20170407.pos	07-04-2017	PIX_BAS_20170407T193112-193912.zip	277.0
PIX_BAS_20170407b.pos	07-04-2017	PIX_BAS_20170407T000002-005956.zip	1,418.3
		PIX_BAS_20170407T010001-015808.zip	1,536.7
		PIX_BAS_20170407T233824-235957.zip	651.0
PIX_BAS_20170408.pos	08-04-2017	PIX_BAS_20170408T010032-014016.zip	2,353.9
		PIX_BAS_20170408T235302-005828.zip	1,237.8
PIX_BAS_20170411.pos	11-04-2017	PIX_BAS_20170411T163713-165958.zip	940.8
		PIX_BAS_20170411T170003-173638.zip	1,642.0
PIX_BAS_20170412.pos	12-04-2017	PIX_BAS_20170412T151012-155637.zip	1,775.7
PIX_BAS_20170413_A.pos	13-04-2017	PIX_BAS_20170413T152651-164802.zip	3,175.3
PIX_BAS_20170413_B.pos		PIX_BAS_20170413T175509-181228.zip	941.9
PIX_BAS_20170413_C.pos		PIX_BAS_20170413T181630-193136.zip	2,061.3
PIX_BAS_20170416.pos	16-04-2017	PIX_BAS_20170416T143357-145955.zip	818.0
		PIX_BAS_20170416T150000-155958.zip	1,052.8
		PIX_BAS_20170416T160003-165957.zip	1,556.7
		PIX_BAS_20170416T170002-175959.zip	1,238.3
		PIX_BAS_20170416T180004-181545.zip	462.2
PIX_BAS_20170418.pos	18-04-2017	PIX_BAS_20170418T134412-135957.zip	660.7
		PIX_BAS_20170418T140002-145958.zip	2,583.1
		PIX_BAS_20170418T150003-155955.zip	2,164.5
		PIX_BAS_20170418T160000-165958.zip	2,541.4
		PIX_BAS_20170418T170003-171323.zip	549.1
PIX_BAS_20170420A.pos	20-04-2017	PIX_BAS_20170420T143804-150429.zip	765.9
PIX_BAS_20170420B.pos	20-04-2017	PIX_BAS_20170420T163249-165957.zip	934.7
		PIX_BAS_20170420T170002-175732.zip	2,159.3
PIX_BAS_20170424.pos	24-04-2017	PIX_BAS_20170424T164647-165957.zip	636.7
		PIX_BAS_20170424T170002-175957.zip	2,645.6
		PIX_BAS_20170424T180002-180957.zip	387.7

21 APPENDIX Processed KAREN data

Date	DOY	File name	Size (MB)
19-03-2017	78	20170319T112530_20170319T112734_levb.nc	15.3
		20170319T112759_20170319T112856_levb.nc	6.8
		20170319T112909_20170319T112944_levb.nc	4.3
		20170319T134213_20170319T135129_levb.nc	763
		20170319T135322_20170319T135853_levb.nc	392
		20170319T140057_20170319T141319_levb.nc	842
		20170319T141629_20170319T142220_levb.nc	754
		20170319T143342_20170319T144750_levb.nc	755
		20170319T151231_20170319T151650_levb.nc	39.2
		20170319T151808_20170319T152326_levb.nc	31.8
20-03-2017	79	20170320T141519_20170320T142517_levb.nc	67.7
		20170320T142858_20170320T144116_levb.nc	318
		20170320T170829_20170320T172829_levb.nc	228
		20170320T172937_20170320T173940_levb.nc	108
		20170320T180818_20170320T181000_levb.nc	8.1
		20170320T181333_20170320T181432_levb.nc	4.6
21-03-2017	80	20170321T104910_20170321T110900_levb.nc	261
		20170321T114323_20170321T114633_levb.nc	32.8
		20170321T114654_20170321T121654_levb.nc	390
		20170321T121804_20170321T123828_levb.nc	266
		20170321T124024_20170321T125358_levb.nc	164
		20170321T130346_20170321T130726_levb.nc	24.7
		20170321T131053_20170321T133007_levb.nc	162
		20170321T133414_20170321T134432_levb.nc	80.7
		20170321T135108_20170321T140009_levb.nc	69.9
		20170321T140904_20170321T142917_levb.nc	145
		20170321T143028_20170321T145054_levb.nc	157
		20170321T145222_20170321T145631_levb.nc	45.4
		20170321T160835_20170321T162833_levb.nc	262
		20170321T163008_20170321T170006_levb.nc	351
		20170321T171329_20170321T171449_levb.nc	13.2
		20170321T174729_20170321T181740_levb.nc	337
		20170321T182001_20170321T190206_levb.nc	183
		20170321T190504_20170321T190904_levb.nc	47.3
		20170321T191725_20170321T194730_levb.nc	205
		20170321T195102_20170321T202105_levb.nc	285
		20170321T202359_20170321T203219_levb.nc	90.5
22-03-2017	81	20170322T145001_20170322T145812_levb.nc	54.6
		20170322T145841_20170322T150953_levb.nc	76
		20170322T151119_20170322T152122_levb.nc	67
		20170322T152229_20170322T153320_levb.nc	75.9
		20170322T153427_20170322T154354_levb.nc	661

		20170322T154943_20170322T160430_levb.nc	1700
		20170322T161058_20170322T162908_levb.nc	786
		20170322T163118_20170322T163549_levb.nc	245
		20170322T164135_20170322T170144_levb.nc	1100
		20170322T171220_20170322T171610_levb.nc	316
24-03-2017	83	20170324T145352_20170324T152348_levb.nc	174
		20170324T152402_20170324T154216_levb.nc	103
		20170324T154229_20170324T161241_levb.nc	169
		20170324T161252_20170324T162750_levb.nc	84.8
		20170324T162806_20170324T165805_levb.nc	208
		20170324T165818_20170324T172145_levb.nc	202
		20170324T173155_20170324T180153_levb.nc	207
		20170324T181336_20170324T181503_levb.nc	7.3
		20170324T182151_20170324T184113_levb.nc	130
		20170324T184142_20170324T185819_levb.nc	110
		20170324T191430_20170324T193400_levb.nc	109
		20170324T193656_20170324T194437_levb.nc	42.3
27-03-2017	86	20170327T140415_20170327T141002_levb.nc	47.7
		20170327T141144_20170327T142007_levb.nc	63.1
		20170327T143544_20170327T143740_levb.nc	14.6
		20170327T143815_20170327T144811_levb.nc	75.9
		20170327T144827_20170327T150043_levb.nc	95.2
		20170327T150206_20170327T151203_levb.nc	81.7
		20170327T151309_20170327T151748_levb.nc	35.1
		20170327T151759_20170327T153807_levb.nc	187
		20170327T153820_20170327T154508_levb.nc	54.4
		20170327T155115_20170327T161116_levb.nc	177
		20170327T161227_20170327T163235_levb.nc	197
		20170327T163256_20170327T163551_levb.nc	22.7
		20170327T164023_20170327T170024_levb.nc	168
		20170327T170103_20170327T170658_levb.nc	43.1
		20170327T170716_20170327T171147_levb.nc	33.5
		20170327T171313_20170327T171723_levb.nc	30.7
		20170327T171944_20170327T172940_levb.nc	73.2
		20170327T173057_20170327T173342_levb.nc	20.3
		20170327T173415_20170327T174647_levb.nc	116
		20170327T174719_20170327T175138_levb.nc	33.1
28-03-2017	87	20170328T140607_20170328T140834_levb.nc	34.9
		20170328T141101_20170328T141210_levb.nc	21.4
		20170328T141905_20170328T143726_levb.nc	195
		20170328T143851_20170328T144524_levb.nc	189
		20170328T145832_20170328T145855_levb.nc	2.8
		20170328T151528_20170328T151626_levb.nc	24.9
		20170328T151939_20170328T152354_levb.nc	591
		20170328T152447_20170328T153827_levb.nc	1900
		20170328T154035_20170328T154955_levb.nc	693

		20170328T155656_20170328T162652_levb.nc	1300
		20170328T163213_20170328T165723_levb.nc	1100
		20170328T165739_20170328T170235_levb.nc	210
29-03-2017	88	20170329T134011_20170329T140006_levb.nc	110
		20170329T140321_20170329T142317_levb.nc	75.8
		20170329T150602_20170329T151418_levb.nc	592
		20170329T153148_20170329T153228_levb.nc	10
		20170329T153314_20170329T153849_levb.nc	701
		20170329T154123_20170329T155343_levb.nc	1500
		20170329T162314_20170329T164310_levb.nc	107
		20170329T164322_20170329T171722_levb.nc	181
		20170329T172047_20170329T175041_levb.nc	181
31-03-2017	90	20170331T090724_20170331T094144_levb.nc	180
		20170331T094203_20170331T101205_levb.nc	155
		20170331T101430_20170331T104620_levb.nc	199
		20170331T104652_20170331T105245_levb.nc	27.5
		20170331T105715_20170331T110326_levb.nc	41.8
		20170331T145126_20170331T145659_levb.nc	218
		20170331T145710_20170331T150705_levb.nc	456
		20170331T150717_20170331T151812_levb.nc	519
		20170331T152259_20170331T152402_levb.nc	9.3
		20170331T153253_20170331T153606_levb.nc	92
		20170331T153622_20170331T155225_levb.nc	998
		20170331T170431_20170331T170500_levb.nc	6.3
		20170331T170802_20170331T170859_levb.nc	9.5
		20170331T171221_20170331T171325_levb.nc	19.3
01-04-2017	91	20170401T104255_20170401T104829_levb.nc	116
		20170401T104842_20170401T111123_levb.nc	1100
		20170401T111134_20170401T111258_levb.nc	17.8
		20170401T111805_20170401T111933_levb.nc	14.6
		20170401T112643_20170401T112810_levb.nc	13
		20170401T112821_20170401T115027_levb.nc	912
		20170401T115214_20170401T115505_levb.nc	35.1
		20170401T115519_20170401T121528_levb.nc	835
		20170401T121549_20170401T122745_levb.nc	401

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Date	DOY	File name	Size (MB)
05-04-2017	95	20170405T213754_20170405T214951_levb.nc	190
		20170405T215525_20170405T220823_levb.nc	201
		20170405T221401_20170405T222544_levb.nc	212
		20170405T223027_20170405T224226_levb.nc	205
		20170405T224942_20170405T230127_levb.nc	200
		20170405T230625_20170405T231835_levb.nc	197
		20170405T232313_20170405T233415_levb.nc	197
		20170405T233742_20170405T233847_levb.nc	13.1
07-04-2017	97	20170407T192536_20170407T192756_levb.nc	57.9
		20170407T233847_20170407T234926_levb.nc	184
		20170407T235209_20170407T235549_levb.nc	63.1
		20170407T235908_20170408T000810_levb.nc	124
		20170408T001959_20170408T003004_levb.nc	305
		20170408T003215_20170408T003956_levb.nc	129
		20170408T005231_20170408T010046_levb.nc	221
		20170408T010607_20170408T011354_levb.nc	183
		20170408T011522_20170408T012245_levb.nc	148
		20170408T012502_20170408T013227_levb.nc	151
		20170408T013345_20170408T014245_levb.nc	179
		20170408T014400_20170408T015257_levb.nc	182
		20170408T015442_20170408T015841_levb.nc	87.4
08-04-2017	98	20170408T233502_20170408T233543_levb.nc	12.7
		20170408T233822_20170408T234547_levb.nc	195
		20170408T234709_20170408T234957_levb.nc	32.3
		20170408T235236_20170409T000054_levb.nc	**210**
		20170409T000242_20170409T001126_levb.nc	180
		20170409T001427_20170409T002254_levb.nc	210
		20170409T002539_20170409T002820_levb.nc	51
		20170409T003055_20170409T003502_levb.nc	52
		20170409T003726_20170409T004008_levb.nc	54
		20170409T004227_20170409T004636_levb.nc	37
		20170409T004933_20170409T005214_levb.nc	60
		20170409T005357_20170409T005808_levb.nc	62
		20170409T010021_20170409T010249_levb.nc	56
		20170409T010432_20170409T010821_levb.nc	59
		20170409T011044_20170409T011252_levb.nc	50
		20170409T011503_20170409T011832_levb.nc	52
		20170409T012018_20170409T012209_levb.nc	47
		20170409T012404_20170409T013034_levb.nc	110
		20170409T013236_20170409T014101_levb.nc	250
11-04-2017	101	20170411T163647_20170411T165309_levb.nc	104
		20170411T165356_20170411T171315_levb.nc	112
		20170411T171327_20170411T173312_levb.nc	106
		20170411T173326_20170411T173609_levb.nc	13.3

12-04-2017	102	20170412T151016_20170412T152549_levb.nc	180
		20170412T152601_20170412T153854_levb.nc	106
		20170412T153938_20170412T155611_levb.nc	267
13-04-2017	103	20170413T140145_20170413T141605_levb.nc	108
		20170413T142704_20170413T143734_levb.nc	87.2
		20170413T143801_20170413T144848_levb.nc	110
		20170413T144901_20170413T145829_levb.nc	77.9
		20170413T145841_20170413T150812_levb.nc	56.6
		20170413T150843_20170413T151823_levb.nc	73.6
		20170413T151836_20170413T153330_levb.nc	90.5
		20170413T153343_20170413T154753_levb.nc	146
		20170413T154804_20170413T160945_levb.nc	211
		20170413T160957_20170413T162859_levb.nc	157
		20170413T162910_20170413T164757_levb.nc	275
		20170413T165404_20170413T171032_levb.nc	230
		20170413T171044_20170413T172737_levb.nc	190
		20170413T172749_20170413T174751_levb.nc	230
		20170413T174807_20170413T175901_levb.nc	100
		20170413T175913_20170413T181205_levb.nc	95
		20170413T181216_20170413T182345_levb.nc	86
		20170413T182357_20170413T183540_levb.nc	110
		20170413T183558_20170413T185319_levb.nc	190
		20170413T190833_20170413T191419_levb.nc	210
		20170413T192741_20170413T193134_levb.nc	120
16-04-2017	106	20170416T134523_20170416T135806_levb.nc	103
		20170416T135818_20170416T141450_levb.nc	214
		20170416T141501_20170416T142330_levb.nc	92.6
		20170416T142407_20170416T143202_levb.nc	121
		20170416T143222_20170416T144853_levb.nc	237
		20170416T145233_20170416T150936_levb.nc	295
		20170416T151110_20170416T152414_levb.nc	239
		20170416T152619_20170416T154146_levb.nc	168
		20170416T160609_20170416T161714_levb.nc	132
		20170416T161728_20170416T162920_levb.nc	182
		20170416T162932_20170416T164229_levb.nc	112
		20170416T164245_20170416T165257_levb.nc	95.6
		20170416T165309_20170416T170314_levb.nc	95.6
		20170416T170325_20170416T171314_levb.nc	113
		20170416T171326_20170416T172553_levb.nc	86.5
		20170416T172608_20170416T173709_levb.nc	65.1
		20170416T173721_20170416T175017_levb.nc	190
		20170416T175201_20170416T180823_levb.nc	841
		20170416T180843_20170416T181501_levb.nc	253
18-04-2017	108	20170418T135016_20170418T140221_levb.nc	137
		20170418T140234_20170418T141226_levb.nc	55.1
		20170418T142524_20170418T142822_levb.nc	21.7
		20170418T143134_20170418T143743_levb.nc	65.8
		20170418T143930_20170418T144343_levb.nc	32.7
		20170418T144404_20170418T144609_levb.nc	13
		20170418T144755_20170418T145442_levb.nc	54.4

		20170418T145629_20170418T150226_levb.nc	43.7
		20170418T150359_20170418T151107_levb.nc	60.7
		20170418T151217_20170418T151854_levb.nc	62.4
		20170418T152023_20170418T152651_levb.nc	49.4
		20170418T152842_20170418T153456_levb.nc	52.5
		20170418T153638_20170418T154313_levb.nc	55.4
		20170418T155020_20170418T155623_levb.nc	61
		20170418T155837_20170418T160527_levb.nc	127
		20170418T160545_20170418T161457_levb.nc	116
		20170418T161519_20170418T162603_levb.nc	142
		20170418T162616_20170418T163537_levb.nc	195
		20170418T163718_20170418T164256_levb.nc	121
		20170418T164347_20170418T165115_levb.nc	162
		20170418T165127_20170418T170024_levb.nc	117
		20170418T170040_20170418T170836_levb.nc	112
		20170418T170912_20170418T171027_levb.nc	7.1
24-04-2017	114	20170424T162943_20170424T163854_levb.nc	921
		20170424T163952_20170424T164752_levb.nc	707
		20170424T164853_20170424T165811_levb.nc	117
		20170424T165836_20170424T170721_levb.nc	101
		20170424T170734_20170424T171616_levb.nc	93.8
		20170424T171629_20170424T172516_levb.nc	110
		20170424T172533_20170424T173432_levb.nc	173
		20170424T173444_20170424T174343_levb.nc	129
		20170424T174354_20170424T175311_levb.nc	189
		20170424T175324_20170424T180211_levb.nc	117
		20170424T180225_20170424T181406_levb.nc	254
25-04-2017	115	20170425T102824_20170425T104442_levb.nc	2200
		20170425T104737_20170425T105253_levb.nc	174
		20170425T115656_20170425T120507_levb.nc	377
26-04-2017	116	20170426T084727_20170426T085738_levb.nc	656
		20170426T085816_20170426T090328_levb.nc	390
		20170426T090404_20170426T090705_levb.nc	227
		20170426T090758_20170426T091406_levb.nc	461
		20170426T091418_20170426T092823_levb.nc	1300
		20170426T092950_20170426T093451_levb.nc	198
		20170426T093726_20170426T094625_levb.nc	267
		20170426T094903_20170426T095043_levb.nc	13.8
		20170426T095737_20170426T100321_levb.nc	280
		20170426T101544_20170426T102132_levb.nc	284
		20170426T102515_20170426T103119_levb.nc	234
		20170426T103446_20170426T104037_levb.nc	262
		20170426T104340_20170426T104843_levb.nc	175
		20170426T105358_20170426T105951_levb.nc	199
		20170426T110853_20170426T111510_levb.nc	238
		20170426T111744_20170426T112503_levb.nc	240
		20170426T112853_20170426T113457_levb.nc	251
		20170426T113929_20170426T114440_levb.nc	310

22 APPENDIX Processed ASIRAS data

The following recorded data are available for the ASIRAS radar system and given in the ESA format described in Cullen (2010).

Date	DOY	File name	Size (MB)
19-03-2017	78	AS6OA00_ASIWL1B040320170319T091111_20170319T091215_0001.DBL	1.7
		AS6OA01_ASIWL1B040320170319T111001_20170319T112951_0001.DBL	30.7
20-03-2017	79	AS6OA00_ASIWL1B040320170320T111135_20170320T144307_0001.DBL	312.2
		AS6OA01_ASIWL1B040320170320T170611_20170320T174033_0001.DBL	51.6
21-03-2017	80	AS6OA00_ASIWL1B040320170321T103056_20170321T145631_0001.DBL	381.5
		AS6OA01_ASIWL1B040320170321T160529_20170321T203821_0001.DBL	398.9
24-03-2017	83	AS6OA00_ASIWL1B040320170324T142820_20170324T194516_0001.DBL	423.7
27-03-2017	86	AS6OA00_ASIWL1B040320170327T135900_20170327T181741_0001.DBL	409.2
28-03-2017	87	AS6OA00_ASIWL1B040320170328T135837_20170328T144625_0001.DBL	61.2
		AS6OA01_ASIWL1B040320170328T151757_20170328T171842_0001.DBL	183.5
29-03-2017	88	AS6OA00_ASIWL1B040320170329T132551_20170329T143431_0001.DBL	107.9
		AS6OA01_ASIWL1B040320170329T143832_20170329T144221_0001.DBL	4.2
		AS6OA02_ASIWL1B040320170329T144831_20170329T145138_0001.DBL	2.5
		AS6OA03_ASIWL1B040320170329T145210_20170329T152353_0001.DBL	34.5
		AS6OA04_ASIWL1B040320170329T153052_20170329T161746_0001.DBL	60
		AS6OA05_ASIWL1B040320170329T161932_20170329T175059_0001.DBL	94.8
30-03-2017	89	AS6OA00_ASIWL1B040320170330T115810_20170330T120728_0001.DBL	12.9
		AS6OA01_ASIWL1B040320170330T122245_20170330T152741_0001.DBL	266.9
		AS6OA02_ASIWL1B040320170330T155449_20170330T155949_0001.DBL	6.7
31-03-2017	90	AS6OA00_ASIWL1B040320170331T090044_20170331T110329_0001.DBL	183.8
		AS6OA01_ASIWL1B040320170331T143546_20170331T155542_0001.DBL	123.5
		AS6OA02_ASIWL1B040320170331T170132_20170331T1709	10.9

		22_0001.DBL	
01-04-2017	91	AS6OA00_ASIWL1B040320170401T103244_20170401T1228 20_0001.DBL	186.7

23 APPENDIX Final ASIRAS profiles

Following plots show all processed ASIRAS profiles using the OCOG retracker. Each profile plot consists of four parts:

1. Header composed of daily profile number and the date and a sub-header with the filename.
2. Geographical plot of the profile (diamond indicates the start of the profile).
3. Rough indication of the heights as determined with the OCOG retracker plotted versus time of day in seconds.
4. Info box with date, start and stop times in hour, minute, seconds, and in square brackets seconds of the day, acquisition mode etc.

It should be emphasized that the surface height determined by the OCOG retracker is a rough estimate and not necessarily a true height.

24APPENDIX KAREN processing documentation