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ESA CryoVEx/EU ICE-ARC 2016 - Airborne field campaign with ASIRAS radar and laser scanner over Austfonna, Fram Strait and the Wandel Sea

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Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Skourup, H., Simonsen, S. B., Sørensen, L. S., Helm, V., Hvidegaard, S. M., Di Bella, A., & Forsberg, R. (2018). *ESA CryoVEx/EU ICE-ARC 2016 - Airborne field campaign with ASIRAS radar and laser scanner over Austfonna, Fram Strait and the Wandel Sea*. Technical University of Denmark.

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ESA CryoVEx/EU ICE-ARC 2016

Airborne field campaign with ASIRAS radar and laser scanner over Austfonna, Fram Strait and the Wandel Sea

H. Skourup, S. B. Simonsen, L. Sandberg Sørensen, V. Helm, S. M. Hvidegaard, A. Di Bella, and R. Forsberg

DTU Space
National Space Institute
Technical University of Denmark

Technical Report,
September 2018

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EUROPEAN SPACE AGENCY CONTRACT REPORT

ESA Contract No. 4000110600/14/NL/FF/lf (CCN3)

ESA CryoVEx/EU ICE-ARC 2016

Airborne field campaign with ASIRAS radar and laser scanner over Austfonna, Fram Strait and the Wandel Sea

Authors:
H. Skourup[1], S. B. Simonsen[1], L. Sandberg Sørensen[1], V. Helm[2], S. M. Hvidegaard[1], A. Di Bella[1] and R. Forsberg[1]

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DTU Space
National Space Institute
Danish Technical University

Technical Report, 2018

ISBN-978-87-91694-41-7

Front page: TF-POF at Station Nord and Romer Lake glacier also known as the Elephant Foot (NE-Greenland), credits S. B. Simonsen

http://www.space.dtu.dk

DTU Space
National Space Institute

ESA STUDY CONTRACT REPORT

ESA CONTRACT NO 4000110600/14/NL/FF/lf (CCN3)	**SUBJECT** Technical Support for airborne ASIRAS and laser scanner measurements during 2016 ESA CryoVEx/EU ICE-ARC campaign		**CONTRACTOR** National Space Institute (DTU Space)
ESA CR No	**STAR CODE**	**No of volumes** 1 **This is Volume No** 1	**CONTRACTORS REFERENCE** CryoVEx 2016

ABSTRACT

This report outlines the airborne field operations with the ESA airborne Ku-band interferometric radar (ASIRAS) and coincident airborne laser scanner (ALS) to acquire gridded data over Austfonna ice cap in Svalbard for CryoSat-2 validation, first direct Sentinel-3A underflight over sea ice in the Fram Strait and additional repeat some previously flown sea tracks in Fram Strait and the Wandel Sea. Vertical photography was acquired during sea ice flights to support analysis of ASIRAS and ALS observations.

The airborne campaign took place April 4-16, 2016, operating out of Svalbard and Station Nord. The campaign was coordinated by DTU Space using the Norlandair Twin Otter (TF-POF). It was partly funded by ESA CryoVEx (Austfonna ice cap flights) and partly by EU FP7 project ICE-ARC (Fram Strait and Wandel sea ice flights). The mobilization costs were shared equally between the projects.

The CryoVEx/ICE-ARC 2016 campaign was a success and the processed data is of high quality. Preliminary comparisons between CryoSat-2 and ALS data at Austfonna ice cap, proves the concept of using a gridded ALS data set of lines parallel to CryoSat-2 ground tracks in areas with varying topography. First direct comparisons of Sentinel-3A and ALS also show consistent results.

The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organisation that prepared it.

Names of authors:
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NAME OF ESA STUDY MANAGER Tânia Casal Mission Science Division Validation Campaigns - ESTEC	**ESA BUDGET HEADING**

DOCUMENT CHANGE LOG

Issue/ Revision	Date	Modified pages	Modification
0.1	01/11 2016	all	Document created, S. B. Simonsen
1.0	30/06 2017	all	Draft delivered to ESA
2.0	24/04 2018	all	Major updates have been made compared to previous versions. This version has been revised including comments given by T. Casal 14/07 2017
2.1	04/09 2018	23/29	Added small paragraph p23 with reference to paper and data from Austfonna flight using 6 different CryoSat-2 retrackers and CryoVEx 2016 laser scanner measurements for validation. Reference added to list of reference p29

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1 Introduction

The 2016 airborne campaign was conducted during April 4-16, 2016, with the ESA airborne Ku-band interferometric radar (ASIRAS), coincident airborne laser scanner (ALS) and vertical photography. It was partly funded by ESA CryoSat-2 Validation Experiment (CryoVEx) and partly by EU FP7 project on Ice, Climate, Economics – Arctic Research on Change (ICE-ARC). As the same aircraft and instrument installation were used for both campaigns this report includes both the CryoVEx and ICE-ARC campaign data. Below is given an overview of which data belongs to which project. The mobilization costs were shared equally between the projects. The campaign was coordinated by National Space Institute, Technical University of Denmark (DTU Space) using a Twin Otter (reg. TF-POF) chartered from Norlandair, Iceland.

The ESA CryoVEx 2016 was primarily carried out to follow up on a recommendation given within ESA CryoVal Land Ice project (2014-2015), where it was found that the traditional under-flights of the Cryosat-2 satellite were inadequate. This is primarily due to uncertainties in the radar-echo location (POCA) due to topography. To account for this effect, the 2016 ESA CryoVEx airborne campaign was aimed at flying dense grids of parallel lines at Austfonna ice cap along CryoSat-2 ground tracks, to cover a broad range of possible POCA locations from different retrackers (CryoVal-LI D4).

The ICE-ARC campaign was mainly used to repeat some previously flown sea ice flights into the Wandel Sea and the Fram Strait, which had partly failed in 2015 due to problems with the ALS logging system. The opportunity was taken to make the first Sentinel-3A under-flight over sea ice in Fram Strait.

This report is the final report and summarizes the airborne field operations, instrument description and data processing together with first results of Austfonna flight and Sentinel-3A underflight. The report is an ESA CryoVEx contract report and part of EU ICE-ARC deliverable 1.62.

1.1 The primary objectives achieved during the campaign

- Land ice validation of CryoSat-2 – Austfonna ice cap, Svalbard to follow up on ESA CryoVal-LI recommendations (ESA CryoVEX).
- First Sentinel-3 underflights over sea ice in Fram Strait (EU FP7 ICE-ARC).
- Monitoring sea ice thickness north of Greenland and Fram Strait, repeat lines (EU FP7 ICE-ARC).
- Overflight of upward looking sonars moored in Fram Strait to support CryoSat-2 sea ice freeboard-to-thickness conversion (EU FP7 ICE-ARC).
- Repeated flights from earlier campaigns, to monitor the interaction between the ice shelf and the buttressing sea ice in the Nioghalvfjerdsfjorden glacier complex (EU FP7 ICE-ARC).

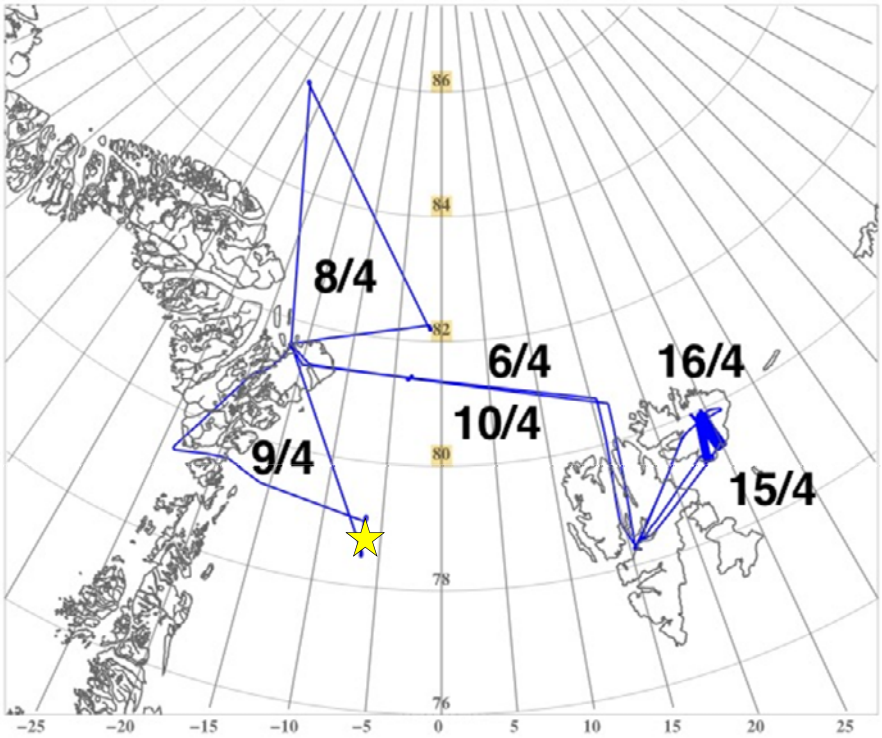

Figure 1 Overview of the flight tracks (blue lines) from the CryoVEx/ICE-ARC 2016 airborne campaign. Dates of the respective flights are marked next to the flight lines. Yellow star marks the location of the NPI Fram Strait ULS buoys.

2 Summary of operation

The CryoVEx/ICE-ARC 2016 airborne campaign was conducted in the period April 4-16, 2016. An overview of the ground tracks of the airborne campaign is presented in Figure 1. The campaign was based out of Station Nord (STN), Northeast Greenland, and Longyearbyen (LYR), Svalbard, Norway.

A Norlandair Twin Otter (reg: TF-POF), which is the same aircraft as used throughout previous CryoVEx campaigns, was chartered for the entire campaign. The instrument certification for the aircraft was obtained in 2006 (Hvidegaard and Stenseng, 2006). The flight altitude is typically 300 m above ground level, 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. Due to shared logistics of the Twin Otter with Danish company Polar Logistics Group ApS (POLOG), the installation and de-installation of the ASIRAS radar and laser scanner (ALS) took place in Lufttransport AS hangar in LYR and was performed by DTU Space personnel.

As the first part of the campaign was aimed at measuring sea ice in the proximity of the Station Nord, North-East Greenland the ferry flight was used to seek the opportunity of the first under-flight of ESA Sentinel-3A SAR altimeter only 51 days after the launch. At Station Nord the weather conditions

proved optimal for aerial surveying, despite low temperatures (down to -35°C). The low temperatures resulted in long start-up time for the ALS as fog was frozen on the inside of the instrument window during take-off, preventing the laser to penetrate through the window, see Section 4. Despite the difficulties with the start-up of the scanner, all planned sea-ice flights north of Greenland and in the Fram Strait were surveyed between April 6 and April 10. Unfortunately a planned coincident flight with NASA Operation IceBridge (OIB) was not performed due to unexpected aircraft maintenance of the OIB aircraft. A more detailed description of the flights and first results are given in Section 6.

During the second part of the campaign, the weather presented itself more challenging with Austfonna ice cap covered in low clouds. This together with strong winds postponed the survey flights at Austfonna to the very last days of operations. On April 15 and 16, two dense grids were flown along two CryoSat-2 tracks, during two long flights.

The airborne team consisted of Henriette Skourup (HSK), Louise Sandberg Sørensen (SLSS), and Sebastian B. Simonsen (SSIM). Calibration flights of the instruments over buildings and runways were performed whenever possible. The CryoVEx/ICE-ARC 2016 campaign ended on April 16 where the equipment was uninstalled in Longyearbyen. An overview of the flights is found in Table 1. For clarity specified CryoVEx flights are marked by blue, whereas ICE-ARC flights are left unmarked throughout the report. A day-to-day overview is given in Section 2.1 and operator logs and plots of flight tracks are provided in Appendix A.

The CryoVEx/ICE-ARC 2016 campaign was a success and the scientific community now has another unique collection of measurements to analyze as an extension to the data time series from the previous campaigns.

Table 1 Overview of CryoVEx/ICE-ARC 2016 flights.

Date	DOY	Flight	Track	Take off UTC	Landing UTC	Air-borne	Airborne Accum. [dd:hh:mm]	Survey operator
April 5, 2016	96		Test flight LYR	14:47	15:16	00:29	00:00:29	HSK/SSIM
April 6, 2016	97	a	Test flight LYR	09:55	10:14	00:19	00:00:48	HSK/SSIM
April 6, 2016	97	b	LYR - S3 (#712) - STN	14:03	17:24	03:21	00:04:09	HSK/SSIM
April 8, 2016	99		STN-F1-F2-STN	11:26	16:28	05:02	00:09:11	HSK/SSIM
April 9, 2016	100		STN-ULS-STN	11:03	15:38	04:35	00:13:46	HSK/SSIM
April 10, 2016	101		STN- S3 (#769) – LYR	15:04	18:27	03:23	00:17:09	HSK/SSIM
April 15, 2016	106		LYR - CS2 (#32066) - LYR	08:28	14:08	05:40	00:22:49	SLSS/SSIM
April 16, 2016	107		LYR - CS2 (#31971) - LYR	08:28	14:02	05:34	01:04:23	SLSS/SSIM
Total							**28h 23min**	

2.1 Day to day

The airborne part of CryoVEx/ICE-ARC 2016 progressed as follows:

April 3: Scientists HSK and SSIM CPH to LYR

April 4-5: Installation of equipment and test flight over the fjord together with overflight of calibration building. The ASIRAS PC2 was not operational and had to be bypassed with the help of RST.

April 6: Local test flight in LYR with runway overflight. The flight was successful with ASIRAS only running on PC1. Second flight on route STN following Sentinel-3A orbit 712.

April 7: Low clouds in the area around STN, no flights.

April 8: Triangle flight north of Station Nord (STN-F1-F2-STN). Cold morning (-34°C), caused the scanner to freeze and had to be heated before the flight to make it operational. The weather was excellent for the survey.

April 9: Flight to 79-glacier and moored upward looking sonars in Fram Strait. Slightly warmer this morning, but still problems with ALS condensation, due to cold temperatures. SLSS from Copenhagen to LYR.

April 10: Second Sentinel-3A under flight (orbit 769) on route STN to LYR. Planned CS-2 under flight (orbit 31841) was cancelled, due to low clouds in the area north of Svalbard.

April 11-14: HSK from LYR to Copenhagen.
Windy and cloudy conditions at Austfonna, no survey.

April 15: First Austfonna flight. Despite persistent cloudy conditions at the ice cap a survey of parallel lines of the CS2 orbit 32066, which will pass Austfonna on April 26, were possible. The planned tracks had to be shortened due to clouds on the north side of the ice cap.

April 16: Second Austfonna flight. Again cloudy condition at Austfonna, but it was possible to conduct a survey around the CS2 orbit 31971, which will pass Austfonna on April 19. After the survey the equipment was un-mounted and packed for shipping.

April 17: SLSS and SSIM LYR to Copenhagen.

3 Hardware installation

The installation of the ASIRAS system was identical to the setup used throughout the previous CryoVEx campaigns (see e.g. Hvidegaard et al (2016), Skourup et al (2013a, 2013b)). To support the ASIRAS system a Novatel GPS DL-V3 was kindly loaned from the Alfred Wegener Institute (AWI). The ALS equipment was of type Riegl LMS Q-240i-60. To prevent malfunction of the ALS during the extreme low temperatures (-25°C and below) in the first part of the campaign, the ALS was wrapped with external heater pads. In addition, an external heater fan as well as an electrical heater, were installed in the instrument bay in the rear baggage compartment of the aircraft, see Figure 6. An older version of the ALS Riegl (LMS Q-140i) was carried along as backup unit.

In addition, three geodetic dual-frequency GPS receivers were mounted for precise aircraft positioning. The receivers (AIR1, AIR2 and AIR3) were connected to two separate GPS antennas ("front" and "rear") through antenna beam splitters. The GPS antennas are permanently installed on TF-POF. Receiver types, antenna information, as well as logging rates for the GPS receivers are given below:

- AIR1 Receiver type Javad Delta front antenna logging rate 1 Hz
- AIR2 Receiver type Javad Delta rear antenna logging rate 2 Hz
- AIR3 Receiver type Javad Delta front antenna logging rate 1 Hz

The higher logging rate for AIR2 was chosen to obtain a higher precision for the on-board navigation system. Offsets between GPS antennas and ASIRAS/ALS are given in Table 2.

To record the attitude (pitch, roll and heading) of the aircraft, two inertial navigation systems (INS) were used. The primary unit is a medium grade INS of type Honeywell H-764G. 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 backup INS is provided by an OxTS Inertial+2 integrated GPS-INS unit, with a nominal similar accuracy as the H-764G. The Honeywell INS was connected to the front GPS antenna. During most of the campaign the OxTS used dual antenna setup with the rear GPS antenna as primary antenna.

To collect visual imagery of the surfaces surveyed during the sea ice flights, two cameras were mounted next to the ALS in the rear baggage compartment of the aircraft, see Figure 7. The cameras were a GoPro photo/video camera in time lapse mode (to limit the data volume) and a uEye webcam as backup system. Both collect nadir looking images.

The setup of the instruments in the aircraft is shown in Figure 2 and pictures of the various instruments are shown in Figure 3-7.

Table 2 The dx, dy and dz offsets for the lever arm form the GPS antennas to the origin of the laser scanner, and to the back center of the ASIRAS antenna (see arrow Figure 2).

To laser scanner	dx (m)	dy (m)	dz (m)
- from AIR1/AIR3 (front)	- 3.70	+ 0.52	+ 1.58
- from AIR2/AIR4 (rear)	+ 0.00	- 0.35	+ 1.42

To ASIRAS antenna	dx (m)	dy (m)	dz (m)
- from AIR1/AIR3 (front)	-3.37	+0.47	+2.005
- from AIR2/AIR4 (rear)	+0.33	-0.40	+1.845

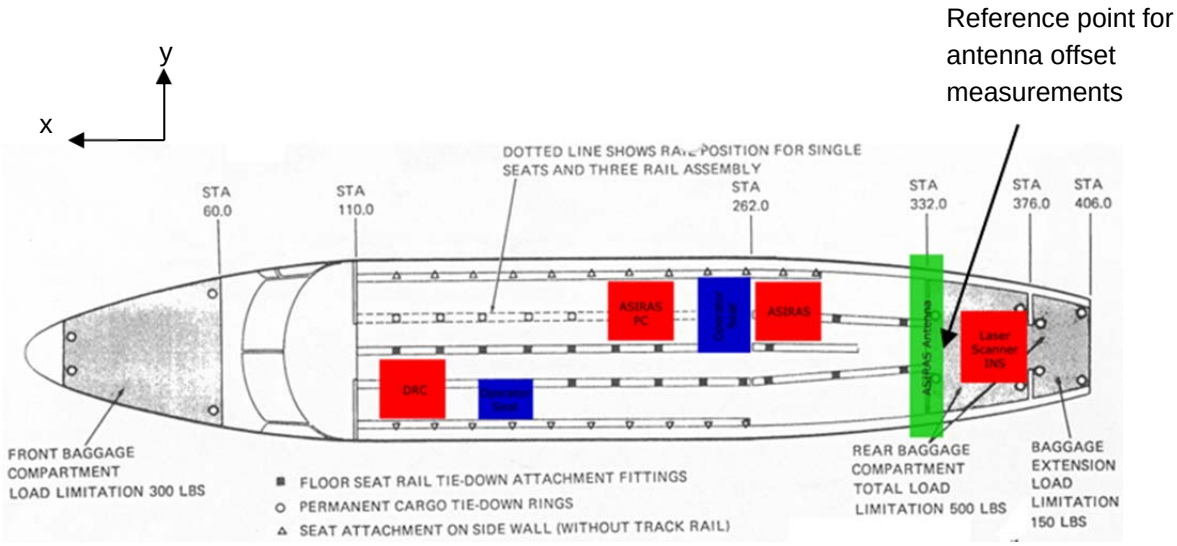

Figure 2 Overview of instrument setup in the TF-POF Twin Otter aircraft.

Figure 3 ASIRAS antenna.

Figure 4 View of cabin in aircraft; Rack with ASIRAS PC's (front right), rack for ALS, GPS and INS (rear left). Spare fuel tank for extra airborne time (front left) Photo: SSIM.

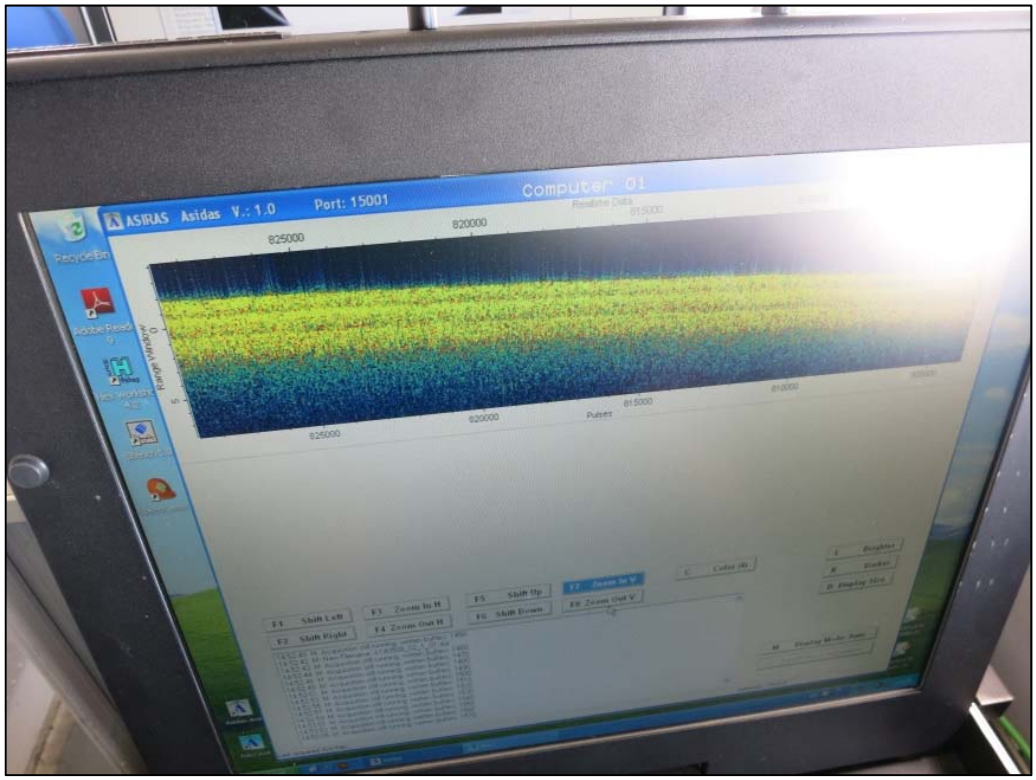

Figure 5 Snapshot of ASIRAS operation display over land ice.

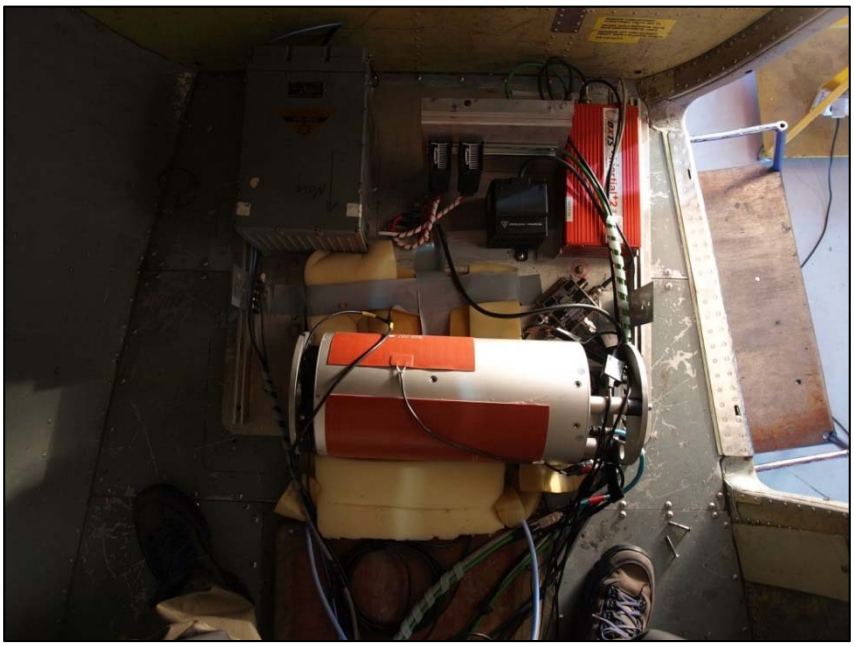

Figure 6 Instrument bay in rear baggage compartment of the aircraft. In front laser scanner RIEGL LMS Q-240i with heater pads (grey/orange instrument). H-764G INS (grey box) and OXTS INS (red box) in the back. Between the two INS instruments are mounted two external heaters.

Figure 7 Photo taken from below through hole in aircraft; visible instruments are laser scanner (purple windows) and nadir looking cameras (left).

4 Overview of acquired data

Data from the various instruments were acquired where feasible, considering the limited height range of the ALS system and the weather. An overview of all acquired data is listed in Table 3.

All the 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 604 TB raw ASIRAS data were collected during the CryoVEx/ICE-ARC 2016 campaign. The data were stored on hard discs as ASIRAS level 0 raw data in the modified compressed format (Cullen, 2010). The ASIRAS system performed well during the campaign only using PC1, due to a malfunction of PC2 detected during the first test flight in Longyearbyen.

In general, the ALS worked well. At low temperatures (below -25^{o}C) encountered at Station Nord, icing of the instrument window during take-off and steep climbs/descends prevented the laser to see through the instrument window. Partly blocking of the laser signals was apparent for the first hour of operation resulting in no surface return or a narrow scan width. Slow climbs during take-off reduced the icing on the scanner window. The actual loss of data was limited since most of the flights included some ferry flight to the designated survey areas. To circumvent the laser to lock on the frozen instrument window, the ALS was switched to measure the “last laser pulse”. 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 7.6 GB ALS data were acquired.

The airborne GPS units logged data internally in the receivers (AIR1, AIR2 and AIR3) during flight, which were downloaded upon landing on laptop PCs. The Novatel GPS was dedicated to support ASIRAS and was not part of the logging system. GPS files were recovered for all receivers at all flights. The GPS reference stations listed in Table 3 are described in further detail in Section 5.1.

Both INS systems logged continuously throughout the campaign and no problems were observed with the systems.

Vertical photography was collected during sea ice flights. Pictures were acquired every 2 seconds for most flights by nadir-looking photography. Due to problems with the data system running the uEye webcam, this camera was only used on the first flight from Longyearbyen to Station Nord. The GoPro camera recorded nadir-photography from the remaining sea ice flights.

All data are stored on external hard discs, as well as the DTU Space servers with tape backup system.

Table 3 Overview of acquired data.

Date	DOY	AIR1	AIR2	AIR3	EGI H-764G	INS OxTS	ALS	ASIRAS	GPS REF1	GPS REF2	uEye	GoPro	Log	Remarks
05-04-2016	96	X	X	X	X	X	X	-	X	-	-	-	X	Test fight LYR
06-04-2016	97a	X	X	X	X	X	X	LAM	X	-	-	-	X	Test fight LYR
06-04-2016	97b	X	X	X	X	X	X	LAMa	-	-	X	-	X	LYR-S3-STN
08-04-2016	99	X	X	X	X	X	X[1]	LAMa	X[2]	-	-	X	X	STN-F1-F2-STN
09-04-2016	100	X	X	X	X	X	X[1]	LAMa	X	-	-	X	X	STN-ULS-STN
10-04-2016	101	X	X	X	X	X	X[1]	LAMa	-	-	-	X[3]	X	STN-S3-LYR
15-04-2016	106	X	X	X	X	X	X	LAMa	X	-	-	-		LYR-CS2-LYR
16-04-2016	107	X	X	X	X	X	X	LAMa		-	-	-		LYR-CS2-LYR

[1] Icing of the scanner window during take-off and steep climbs/descends

[2] The cold conditions made the GPS run out of battery 16:24, but the TF-POF landed at STN 16:28

[3] The GoPro image-file G0017431.jpg was corrupted

5 Processing and final data

The data processing is divided between DTU Space and AWI. ASIRAS data is processed by AWI using GPS and INS data supplied by DTU Space. GPS differential positioning together with combined INS-GPS integration is done by DTU Space followed by processing of laser distance measurement into elevation above a reference ellipsoid. This is supplemented by geo-reference of the images taken along the flights, see Section 5.5.

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

- **CryoVEx flights, Austfonna April 15-16 can be requested at the ESA portal:** https://earth.esa.int/web/guest/campaigns
- **ICE-ARC flights, April 6-10 can be downloaded through:** https://www.ice-arc.eu/data/

5.1 GPS

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 Section 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 base stations in the processing procedure, the PPP method is only based on precise information of satellite clock and orbit errors.

The GPS base stations used as reference stations for differential post processing of the GPS data are listed in Table 4. A Javad Maxor Receiver with internal antenna and logging rate 1 Hz was used as base station. The base station was mounted on DTU Space small tripods (vertical height 12 cm) and placed near the airport before flights.

The positions of the 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 2016 are provided in Appendix B.

Table 4 Overview of CryoVEx/ICE-ARC 2016 GPS reference stations

Name	Site	Site description
STN1	Station Nord	On snow field between building 9 and runway*
LYR1	Longyearbyen	Next to parking lot outside airport for test-flights/Airport next to apron for Austfonna flights

*The usual spot near fuel pump was not used due to fuel-lift (operation northern Falcon)

The GPS processing were performed with Waypoint GrafNav (version 8.30) 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 was selected according to Table 5 and used in the further processing.

5.2 Inertial Navigation System

The position and attitude information (pitch, roll and heading) recovered from the raw Honeywell (H-764G) and the Oxford Inertial 2+ (OxTS) INS data 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 5. As seen, all solutions are based on input from the Honeywell instrument, avoiding solutions based on the OxTS INS, which has degraded accuracy during acceleration, which includes turns and rapid changes of altitude (Skourup et al., 2012).

The best solutions of both GPS and INS data based on Table 5, is packed as binary files in the special ESA file format (Cullen, 2010). An overview of the final GPS and INS files is listed in Appendix F and G with file name convention according to Appendix E.

Table 5 List of best combination of GPS and INS data

Date	DOY	GPS file names	GPS rover	GPS Reference	GPS Processing	INS
05-04-16	96	AIR2REF1/096_AIR2_REF1.p	AIR2	STN1	DIF	H-764G
06-04-16	97a	AIR2REF1/097a_AIR2_REF1.p	AIR2	None	PPP	H-764G
06-04-16	97b	AIR2/097b_AIR2.p	AIR2	None	PPP	H-764G
08-04-16	99	AIR2/099_AIR2.p	AIR2	None	PPP	H-764G
09-04-16	100	AIR2/100_AIR2.p	AIR2	None	PPP	H-764G
10-04-16	101	AIR2/101_AIR2.p	AIR2	None	PPP	H-764G
15-04-16	106	AIR2LYR1/106_AIR2_LYR1.p	AIR2	LYR1	DIF	H-764G
16-04-16	107	AIR2/107_AIR2.p	AIR2	None	PPP	H-764G

5.3 Airborne Laser Scanner

The laser scanner operates with wavelength 904 nm. The pulse repetition frequency is 10,000 Hz and the ALS scans 40 lines per second, thus the data rate is 251 pulses per line. This corresponds to a horizontal resolution of 0.7 m x 0.7 m at a flight height of 300 m and a ground speed of 250 kph. The across-track swath width is roughly equal to the flight height, and the vertical accuracy is in the order of 10 cm depending primarily on uncertainties in the kinematic GPS-solutions. The raw logged files with start /stop times are listed in Appendix C.

5.3.1 Calibration

The calibration of the misalignment angles between ALS and INS can be estimated by analyzing crossovers of a ground segment. The calibration is further assisted by successive overflights from different directions of the same building, where the position of the corners is known with high precision from GPS measurements. These dedicated calibration maneuvers over building have been carried out twice during the 2016 campaign:

- 05-04-2016 DOY 096 Longyearbyen
- 08-04-2016 DOY 099 Station Nord

Examples of calibration overflights of buildings are given in Figure 8 and 9.

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 C.

5.3.2 Laser scanner outlier detection and removal

No major problems were encountered with the instrument. Due to the problems with moisture on the inside of the ALS (see Chapter 4), some of the flights out of Station Nord have reduced scan width down to about 100m. The largest effects were obtained during the first 30-45 minutes of the survey flights until the external and internal heaters had melted the ice. For most of the flights this effect of icing of the scanner window was reduced by setting the instrument to the TS1 mode that detects the last return pulse. Removal of outliers and clouds were done by manual inspection of all data-files using a python program (SkyFilt.py) with an option to automatically remove data points closer than 50m to the aircraft, by using input from processed GPS-heights.

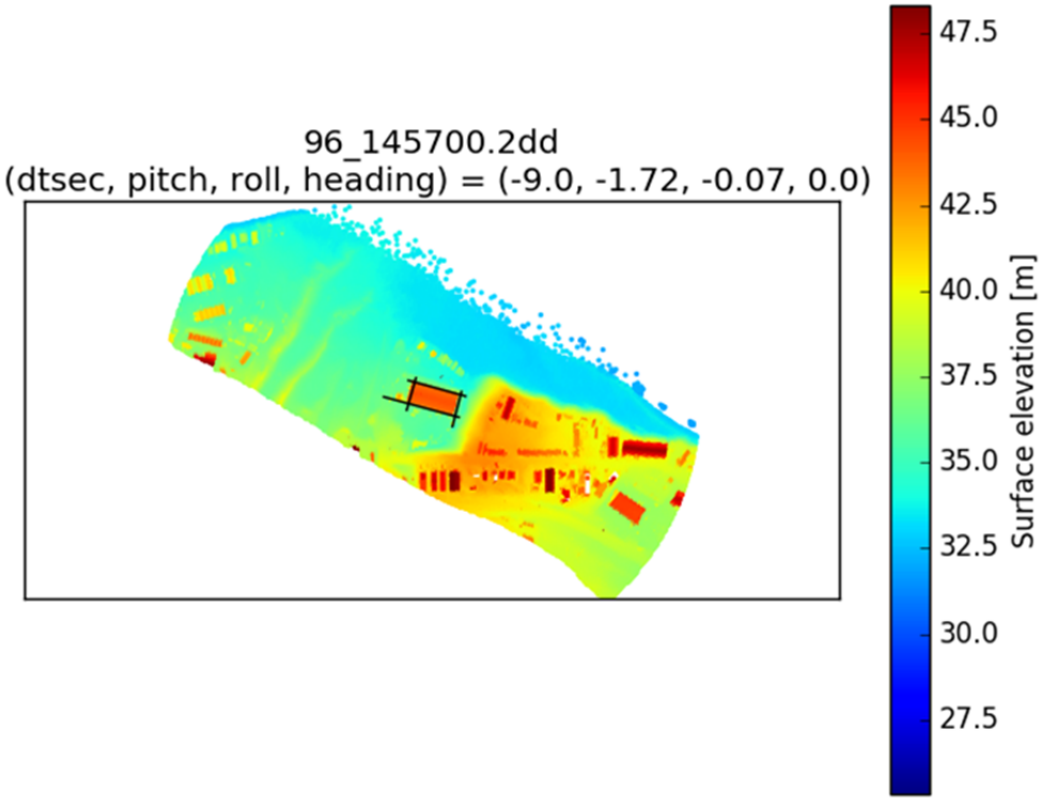

Figure 8 Building overflight in Longyearbyen on April 5. The black lines indicate the in-situ measurements of the building.

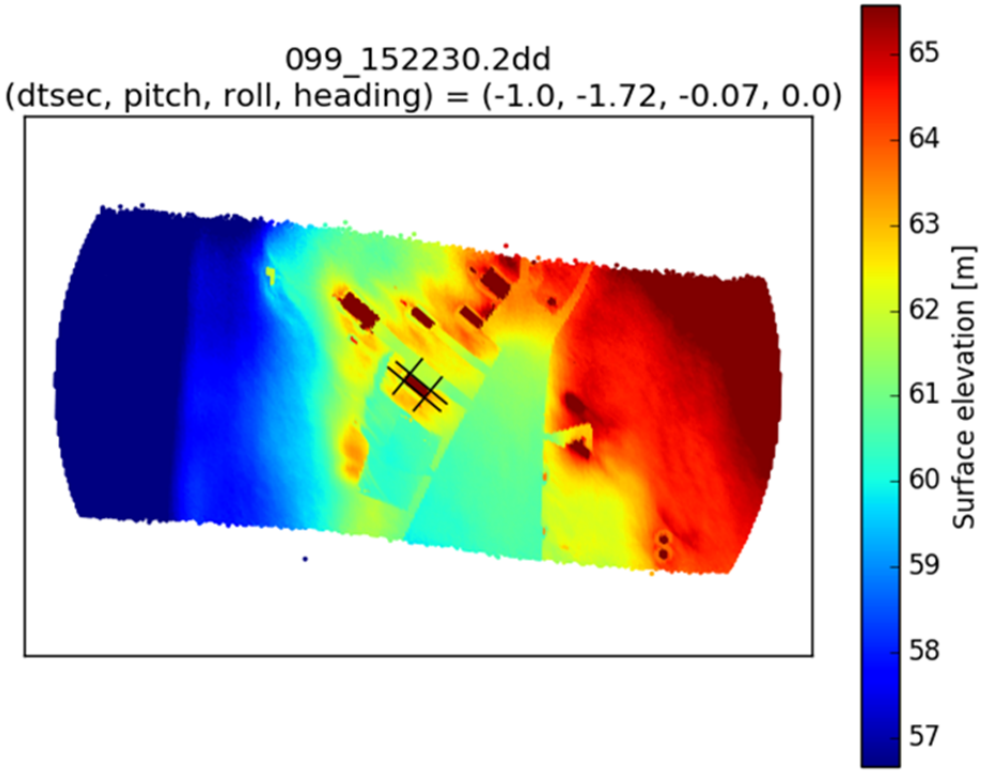

Figure 9 Building overflight at Station Nord on April 8. The black lines indicate the in-situ measurements of the building.

5.3.3 Cross-over statistics

As a part of the processing routine, crossover statistics are derived for all repeated overflights 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-section. The statistics based on raw scanner data before outlier editing are summarized in Table 6, and an example of cross-over differences for Austfonna ice cap is given in Figure 11. Based on statistics from Table 6 it is concluded that the ALS is of high quality with mean differences typically less than 3 cm and standard deviation of cross-over differences less than 10 cm.

5.3.4 Final processed data

Processed 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 see Appendix H. An overview of the processed data is given in Figure 10 together with Appendix I.

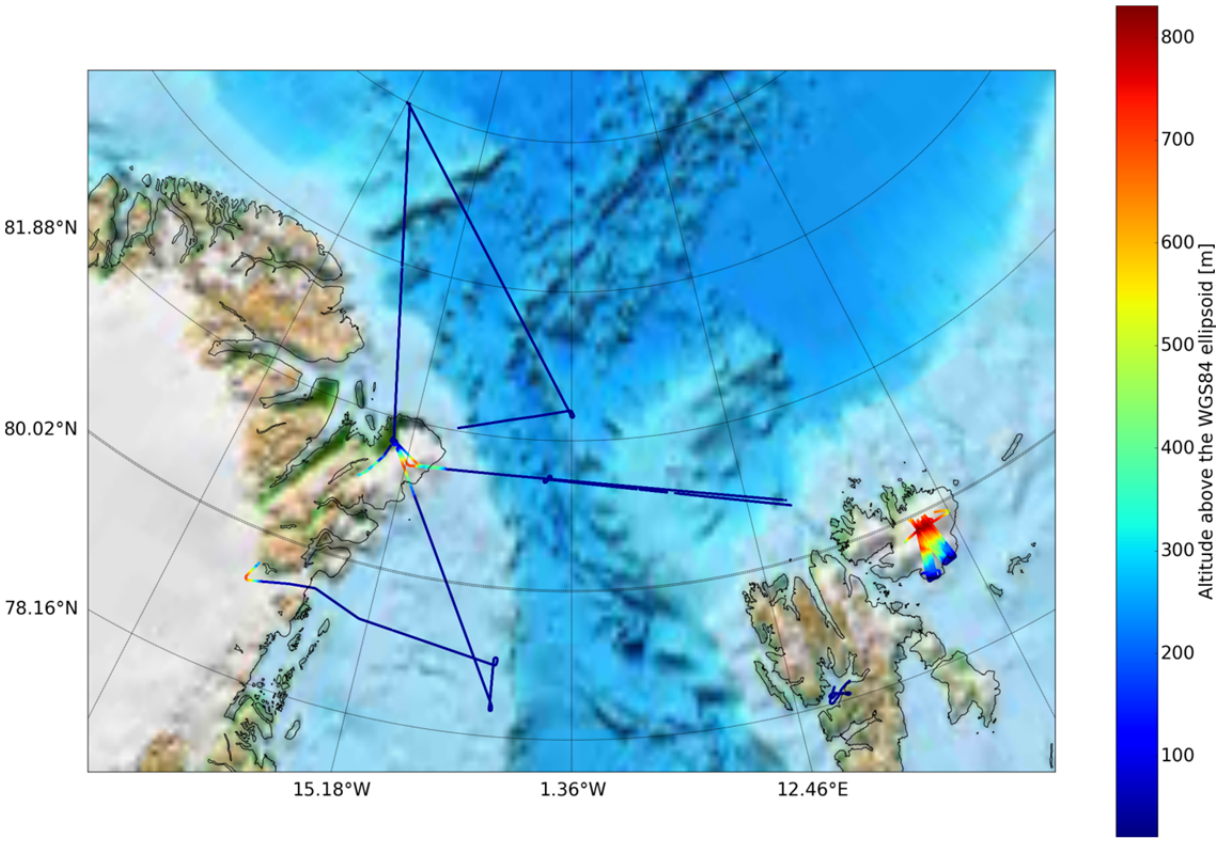

Figure 10 Mission overview of the ALS data, all recorded heights is given as geo-located point-clouds in respect to the WGS-84 reference ellipsoid.

Table 6 Cross-over statistics

Date	DOY	XO number of the day	Mean (m)	St. Dev (m)	Min (m)	Max (m)
05-04-2016	096	0	-0.01	0.08	-0.3	0.29
		3	-0.01	0.07	-0.24	0.23
		5	-0.06	0.05	-0.37	0.12
		6	-0.04	0.06	-0.29	0.14
		7	-0.05	0.05	-0.42	0.34
		9	-0.01	0.07	-0.24	0.23
06-04-2016	097a	0	0.02	0.08	-0.34	0.43
		1	-0.01	0.13	-0.42	0.35
		2	-0.02	0.08	-0.34	0.43
06-04-2016	097b	No suitable XO's during the sea ice flight				
08-04-2016	099	1	0.00	0.09	-0.4	0.4
		3	-0.02	0.08	-0.98	0.75
09-04-2016	100	No suitable XO's during the sea ice flight				
10-04-2016	101	No suitable XO's during the sea ice flight				
15-04-2016	106	1	0.10	0.07	-0.17	0.34
		3	-0.03	0.05	-0.30	0.19
		5	0.01	0.09	-0.46	0.46
		7	0.01	0.08	-0.44	0.44
		8	0.01	0.08	-0.44	0.44
		9	0.02	0.07	-0.61	0.72
		10	0.01	0.08	-0.44	0.44
		11	0.02	0.07	-0.61	0.72
16-04-2016	107	0	0.00	0.06	-0.23	0.28
		1	-0.00	0.05	-0.27	0.24

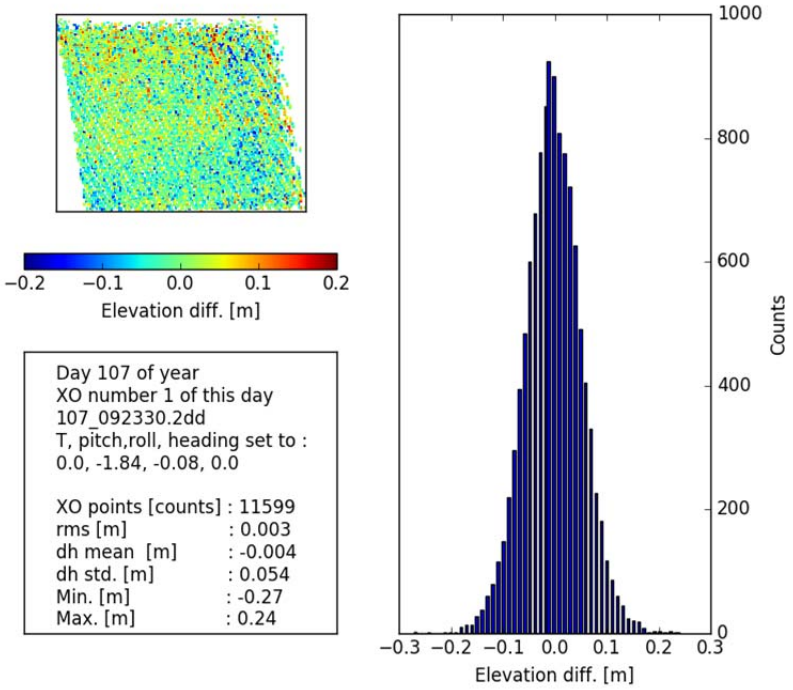

Figure 11 Example of cross-over elevation differences at Austfonna ice cap, April 16, 2016

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. An overview of the acquired ASIRAS log-files together with start/stop times, range window and number of pulses are listed in Appendix D.

5.4.1 CryoVEx 2016 ASIRAS 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 and some sea ice areas, 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 obtain absolute surface heights from ASIRAS an offset needs to be applied to account for internal delays in cables and electronics. As the offset is dependent on the choice of retracker it has not been applied in the ASIRAS Level 1b processing. The offset is estimated by comparing ASIRAS 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.

During the campaign runway overflights was performed at:

- 06-04-2016 DOY 97 Longyearbyen
- 08-04-2016 DOY 99 Station Nord
- 15-04-2016 DOY 106 Longyearbyen

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

5.4.2 Runway overflights and comparison with ALS-DEM

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

The statistics of all successful runway overflights are given Table 7. A total mean difference of 3.53 m ± 0.06 m is found between ALS and ASIRAS elevations by using the OCOG retracker. The last column in Table 7 states how many percentage of the total number of ASIRAS observations is left after observations with roll angles above/below 1.5° has been removed.

Table 7 ASIRAS -over statistics

Profile	Site	Overflight	Start time	End time	# points	Off-set (m)	Std (m)	Roll (%)
A20160406_00	LYR	1	36386	36421	1515	3.48	0.06	89
A20160406_00	LYR	2	36610	36643	1795	3.52	0.06	100
A20160408_05	STN	1	58735	58759	239	3.58	0.06	25
A20160408_05	STN	2	59002	59024	722	3.55	0.05	80
A20160415_06	LYR	1	50401	50440	867	3.52	0.09	71
A20160415_06	LYR	2	50667	50701	1073	3.55	0.07	77

An example of the laser scanner elevations of the runway overflight in Longyearbyen April 6, 2016, 2nd overflight is given in Figure 12 and 13. A swath of the ALS surface elevations of the runway including the ASIRAS profile (black line) and marking of the runway (outlined black box) is shown in Figure 12. The along-track comparison of the ALS surface elevations (blue) and the ASIRAS OCOG retracked elevations (red) is shown in Figure 13 upper left, together with aircraft roll-angles (black) in lower left. The statistical distribution of the offset between the elevations is shown in the histogram (upper right).

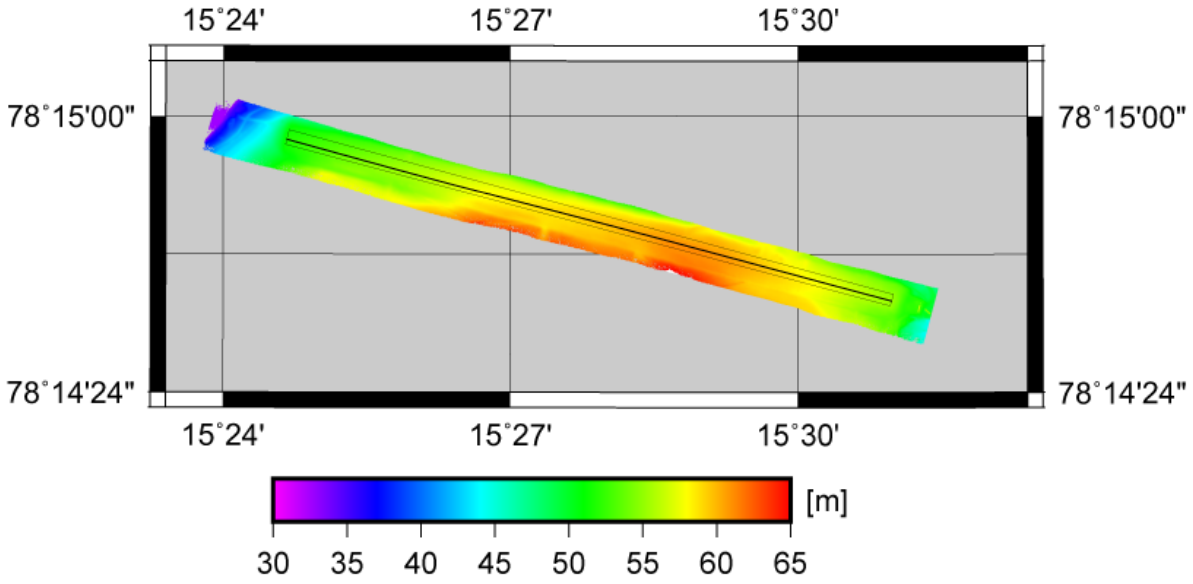

Figure 12 ALS elevation model (w.r.t. WGS-84) of runway in Longyearbyen, April 6, 2016

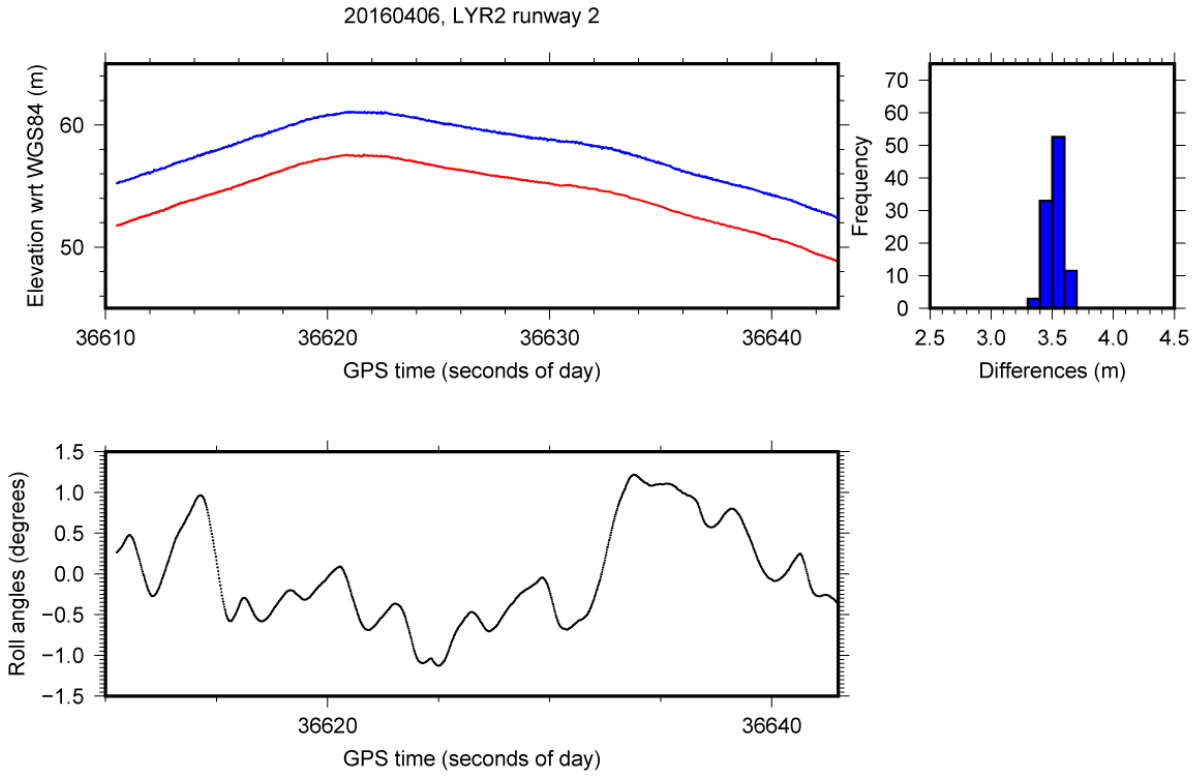

Figure 13 Comparison of ALS and ASIRAS elevations over runway in Longyearbyen, April 6, 2016. ALS elevation in blue and OCOG retracked ASIRAS elevation in red (upper left) and histogram of ALS-ASIRAS elevation differences (upper right). Roll angles are shown in lower plot.

5.4.3 Corner reflector overflight

No corner reflector overflights were performed during the campaign.

5.4.4 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 L and a summary of the processing is given in Appendix M together with plots of each profile.

5.5 Vertical images

To support the analysis of ALS and ASIRAS data over sea ice high-resolution images were collected along the flights.

Two nadir-looking cameras were mounted next to the ALS instrument in the rear baggage compartment, see Figure 14. On the right, a GoPro camera in time lapse mode collected photos at a 2 second interval. Next to this a backup uEye webcam was installed also acquiring images at 2 second interval but with slightly lower resolution. An overview of the properties of the cameras is given in Table 8 and examples are shown in Figure 15. Both cameras were remote controlled and time tagged using the internal PC/camera clock. By combining the time-tag of the images with GPS data the images have been geo-referenced along the flight lines. Positions of each image are given in a position file (see format in Appendix J), and the raw images are packed in zip-files of about 2 MB (see overview Appendix K).

Table 8 Overview of camera types and settings

Camera type	View	Interval (sec)	Resolution (pixels)	Image size (MB)
uEye	Nadir-looking	2	1280x1024	~5
GoPro	Nadir-looking	2	2592x1944	~1.6

Figure 14 Camera installation of nadir-looking cameras for CryoVEx 2016; uEye (left) and GoPro (right).

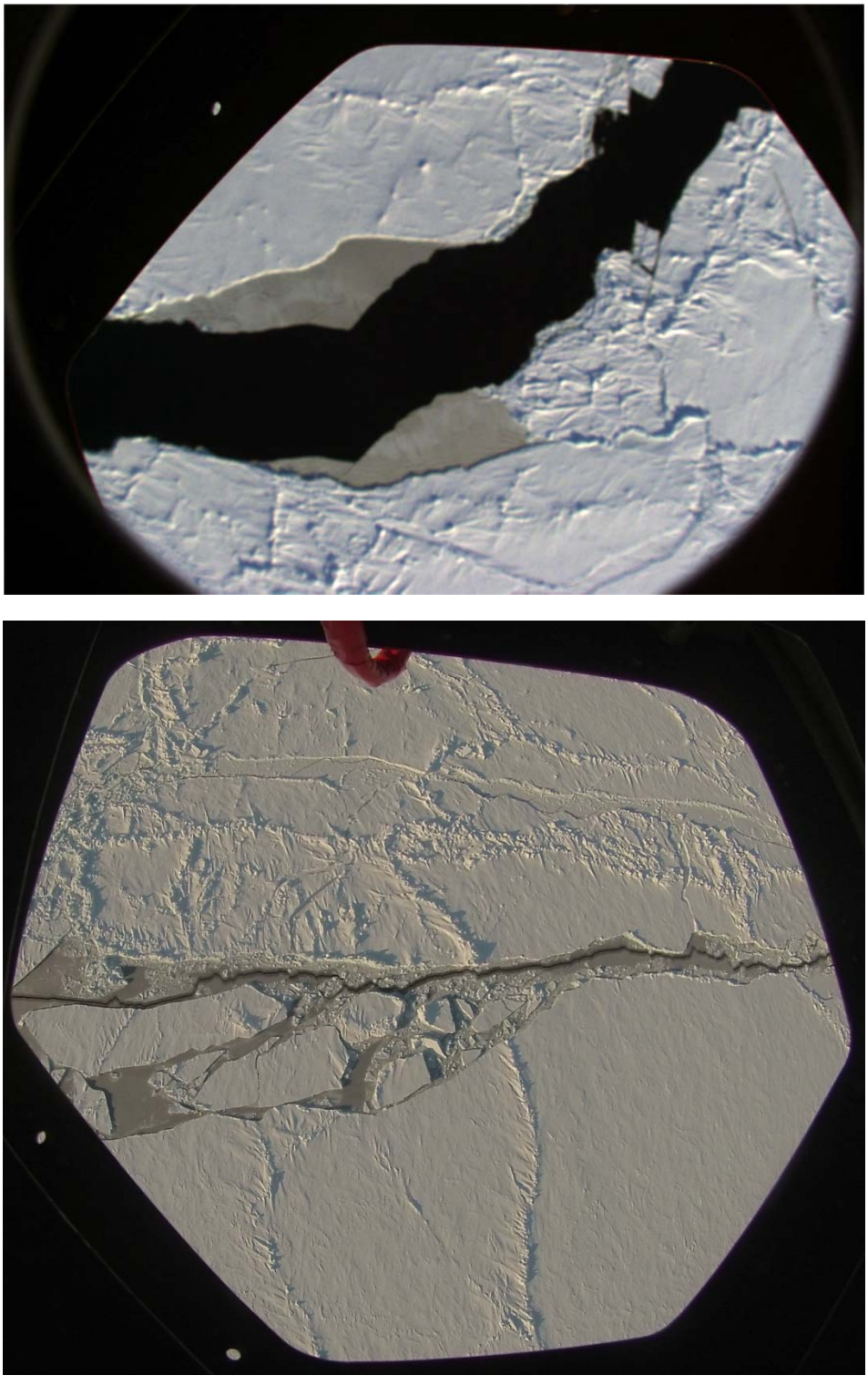

Figure 15 Examples of nadir-looking images.(Upper) uEye image (lower) GoPro.

6 Calibration and validation sites

6.1 Land ice

The primary flights during CryoVEx 2016 airborne campaign were the flights at Austfonna ice cap, see below. As an opportunity, the Nioghalvfjerdsfjorden glacier system was re-flown from EU ICE-ARC 2015 airborne campaign, together with measurements of the local ice cap Flade Isblink (FIB) near Station Nord.

6.1.1 Austfonna

The Austfonna ice cap (Figure 16) was flown on April 15 and 16, 2016. The flight lines were prepared to form a dense grid of parallel lines centered around CS-2 orbits 31971 (eastern) and 32066 (western) tracks with passage dates on April 19 and April 26, respectively. The grid flown at Austfonna, were aimed at covering the total POCA area along the selected CS-2 orbits to make the best possible reference surface for validation of CS-2, and were designed in close collaboration with the ESA CryoVal-Land-Ice team members. Two approaches were tested with line spacing of 1 and 2 km, respectively. In addition, an East-West oriented line (Eton East) was re-flown from previous campaigns. It is seen that the length of the lines were limited towards north; this was a consequence of low clouds in this area of the ice cap.

Unfortunately, it was not possible to coordinate the flights directly with the Norwegian ground team, as they were based on the western most part of the ice cap. However, daily contact by iridium phone with the ground team prior to flights has been invaluable to receive updates on weather conditions.

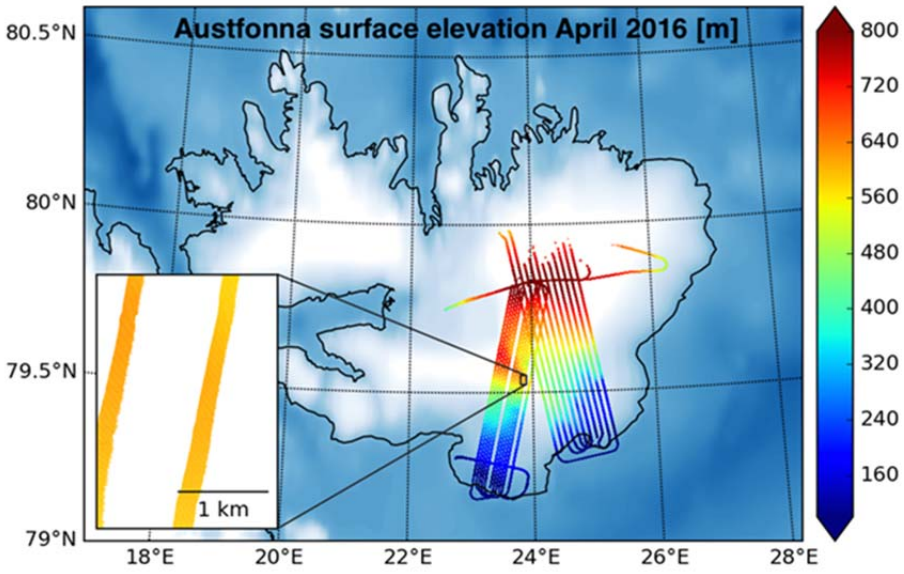

Figure 16 Austfonna ALS surface elevations in meters w.r.t. WGS-84. Insert show the coverage of ALS swaths (~300 m) in the 1 km grid.

Preliminary surface elevations were presented at the ESA Living Planet Symposium by Davidson and Parrinello (2016) and Sørensen et al. (2016). An inter-comparison with ESA Baseline C L2 data and the acquired ALS measurements are shown in Figure 17. First of all it is noticed that all the POCA locations of CryoSat-2 (colored dots) are within the across-track grid spanned by the ALS measurements (green lines). Prior to the comparison the ALS observations were averaged to a resolution of 50m x 50m. Then for each of the POCA locations of CryoSat-2 the nearest neighbor of the averaged ALS observation were found using a 500m search radius. The differences between the POCA located CryoSat-2 elevation and the corresponding ALS elevation are shown as color-coded dots in Figure 17 left. The histograms of elevation differences and time differences between CryoSat-2 and ALS acquisitions are shown in Figure 17 right. There were not found any advantages in using the 1 versus 2 km grid spacing.

The same methodology was used in Sørensen et al. (2018), to analyse six different CryoSat-2 retrackers, including the ESA Baseline C L2 (Figure 17). The supporting on-line material (SOM) of Sørensen et al. provide all CryoSat-2 and ALS data used in the study, along-side the scripts to derive relevant statistics. This valuable CryoVEx dataset may serve as a benchmark for future retracker development for CryoSat-2.

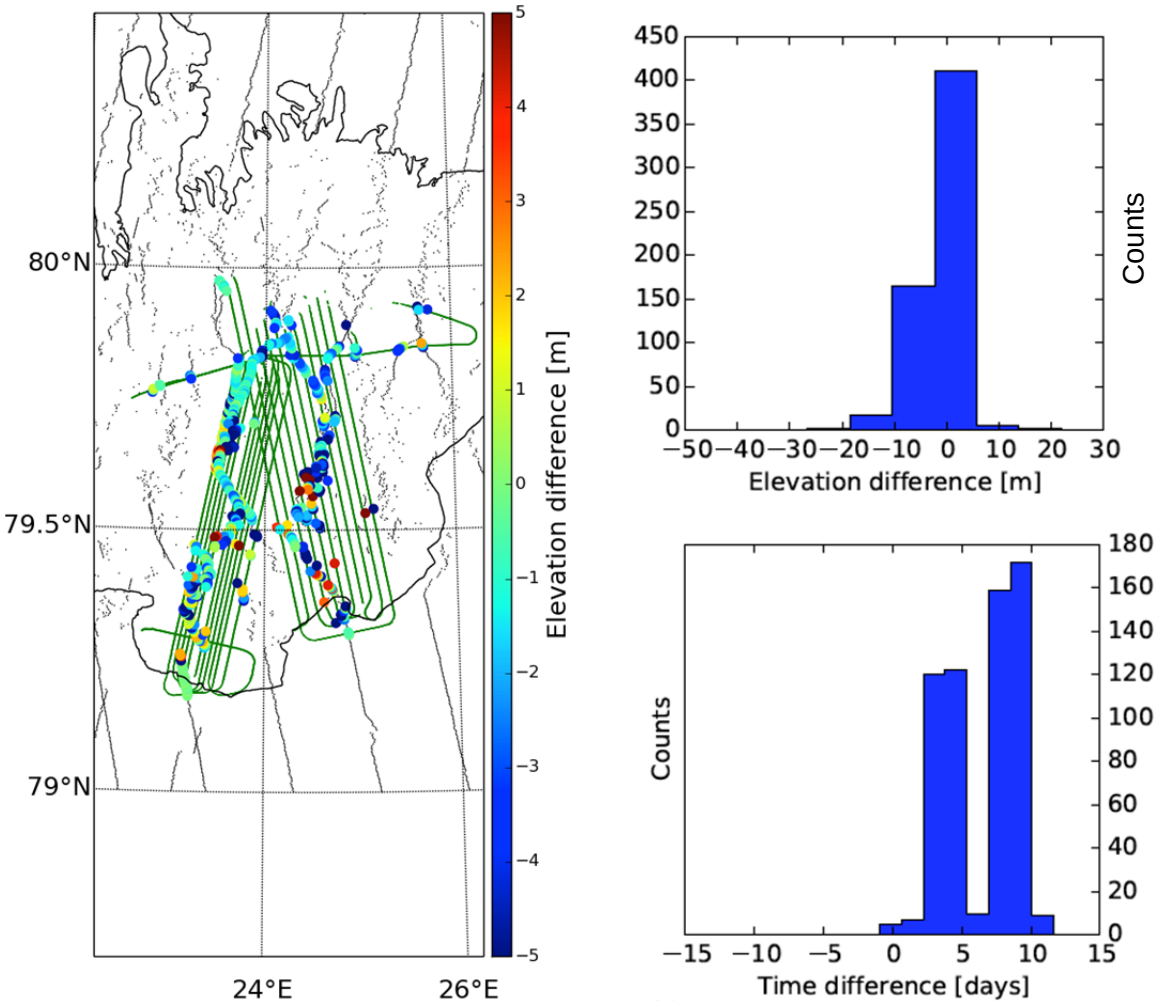

Figure 17 Inter-comparison of ESA Cryosat-2 L2 data and the ALS data obtained in April 2016

6.2 Sea ice

6.2.1 Sentinel-3 underflight

As an opportunity Sentinel-3A (S3A) under-flight over sea ice in Fram Strait was acquired on April 6 along orbit 712. The satellite passed above the aircraft 16:30 UTC at position 81° 24.43'N and 04° 50.03'W. At the passage time only ASIRAS was recording, due to low thick clouds, which appeared on the track 5 minutes before the satellite passage. This direct under-flight of the S3A over sea ice is to our knowledge the first successful under-flight for this satellite.

On transit flight from Station Nord to Longyearbyen, April 10, a planned CryoSat-2 under-flight (orbit 31841) was cancelled due to low clouds in the area north of Svalbard, and instead a second S3A under-flight was prioritized. The flight followed S3A ground track orbit 769 with passage time of the satellite at 16:27 UTC at position 81° 20.24'N 01° 07.00'E. The weather for this flight was excellent and we only encountered low clouds when approaching Svalbard.

ESA has confirmed that S3A operated in SAR-mode on April 6 and provided the respective level 1b products (i.e. waveforms) so that a first comparison with ALS results could be performed. On the flight on April 10 S3A was switched to Low resolution mode (LRM). A preliminary inter-comparison study of S3A and ALS data from underflight on April 6 was presented at AGU fall meeting 2016 by Di Bella et al. (2016). A short update of the presentation is given below. The S3A waveforms have been classified using their pulse peakiness as being generated by reflections from sea ice or leads. While sea ice waveforms have been retracked using a threshold algorithm (TFMRA50%), lead elevations are estimated using a Gaussian retracker.

Elevation profiles from S3A and ALS can be observed in figure 18, where the blue dots in the upper plot show the sea ice elevations retrieved processing S3A data, while those in the bottom plot show the snow elevations obtained from ALS measurements. Both elevations have been detrended using the DTU15 mean sea surface (MSS). The red solid lines in the plots represent the sea surface anomalies (SSA), which have been determined by interpolating along track lead elevations.

Comparing the two profiles, an average bias of a couple of meters can be observed between S3A and ALS elevations. This is due to the geophysical corrections not being available for S3A measurements at the time when the processing was performed.

Additionally, the upper plot shows a series of extremely high elevations, up to 18 m, estimated by S3A around 275 km along track which is not observed in the bottom plot. The cause for these extreme elevations has been investigated by analyzing one of the waveforms, corresponding to the circled point in the upper plot of figure 18. Inset in Figure 18 upper plot shows that the TFMRA50% algorithm retracks the half-power point of the first peak around bin number 10 (green dot) instead of the main one around bin number 45. This kind of waveforms is not unusual in sea-ice-covered areas and might be associated with an iceberg inside the satellite footprint. In this case, however, ALS was

not able to detect the iceberg, possibly due to its smaller footprint. In fact, while S3A coverage extends up to 1.6 km across track, ALS only covers 0.3 km in the same direction.

Overall, a fairly good agreement between S3A and ALS elevations has been found, especially taking into account that, in the situation of snow-covered sea ice, the radar onboard S3A are assumed to measure the height of the snow/ice surface in cold dry snow conditions, whereas ALS measures the height of the snow-air surface.

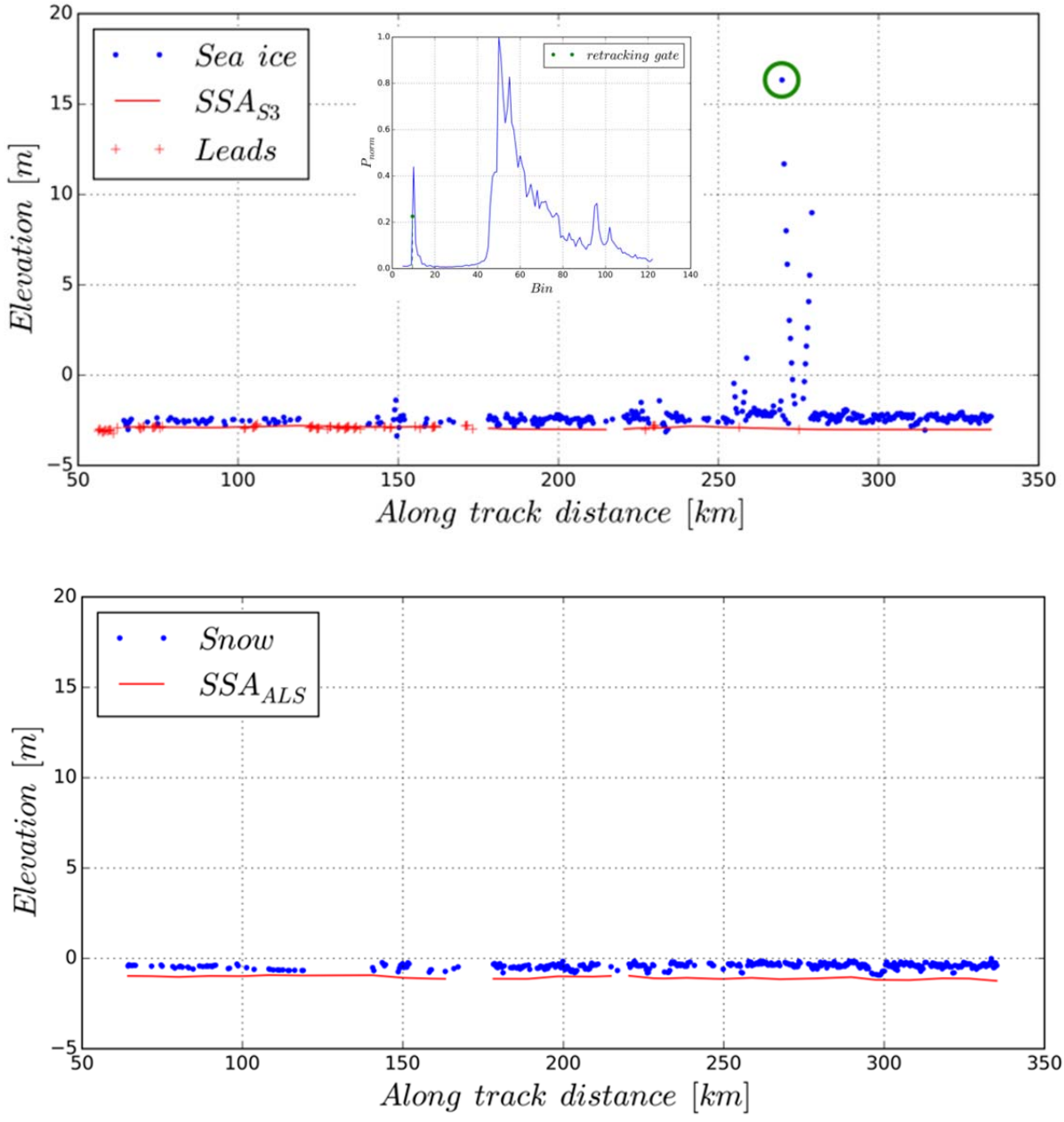

Figure 18 Sentinel-3A sea ice underflight in Fram Strait April 6, 2016. Sentinel-3A (upper plot) and ALS (lower plot).

6.2.2 Triangle flight north of Station Nord

The triangle flight (STN-F1-F2-STN), has been flown repeatedly since 2003, and with a single beam laser in 1998. The primary aim of the 2016 flight was to get continuation in the data set, as there were problems with retrieval of ALS measurements during a similar flight flown within the EU ICE-ARC 2015 campaign.

The first part of the flight STN-F1 was originally planned as a coincident flight with NASA's Operation IceBridge (OIB) P-3 aircraft equipped with multiple sensors for sea ice and snow retrievals, where especially the snow depth radar is valuable for snow depth information to support estimation of ASIRAS penetration depths. Unfortunately this coincident flight was canceled due to unexpected aircraft maintenance of the OIB aircraft.

An example of the distribution of ALS freeboard heights from repeated flight tracks (2003-2016) of the sea ice north of Greenland (81-87°N), was presented at the ESA Living Planet Symposium by S. M. Hvidegaard et al. (2016), and is shown in Figure 19. The data set is unique and covers 13 years of observations – from April or May. The freeboard heights are retrieved from ALS by selecting the lowest values in the track data as described in Hvidegaard et al. (2002). The dotted lines mark datasets not covering the full flight line. Data from various campaigns show an overall thinning of the sea ice with large inter-annual changes overlaid.

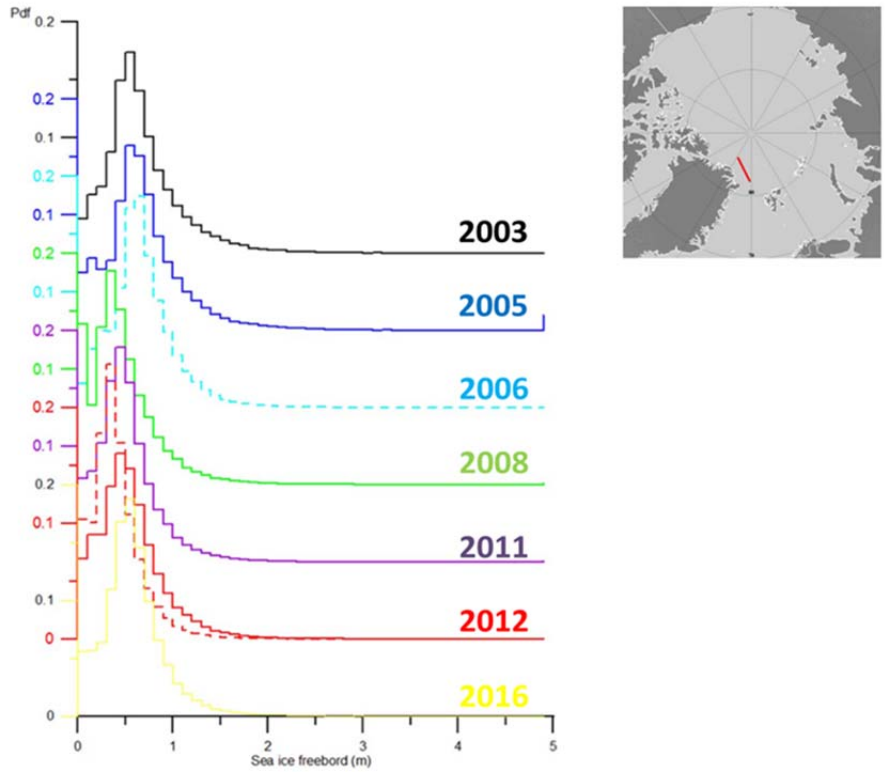

Figure 19 Sea ice freeboard heights from repeated flights north of Station Nord 2003 – 2016.

6.2.3 Upward looking sonars

Norwegian Polar Institute (NPI) maintains an array of upward looking sonar moorings located in the Fram Strait measuring the sea ice draft continuously in time. One of these buoys F14 at position 78 48.87N, 06 30.03W was overflown on April 9, along a straight N/S line to account for sea ice drift, see star in Figure 1. Similar over-flights have been collected in April 2012, 2014, 2015.

The airborne laser and radar measures, the sea ice freeboard (Hvidegaard and Forsberg (2002)), as is the case for CryoSat-2. Where the laser reflects on the top of the snow layer, the radar penetrates partly into the snow layer, depending on the snow conditions (Gerland et al. (2013), Hendricks et al. (2010), Willatt et al. (2011)). Thus, a combination of the airborne measurements complements the ULS measurements from below the ice to give an estimate of the thicknesses of the sea ice. 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, to support CryoSat-2 sea ice thickness estimates. The data from the ULS have not yet been studied as there always is a lack in the availability of the buoy data, as these needs to be physically removed to download data.

Figure 20 Large scale snow drift pattern on sea ice, Fram Strait, April 2016.

7 Conclusion

The CryoVEx/ICE-ARC 2016 airborne campaign has been a success. In general, the weather was good in Greenland, which allowed data acquisition from all planned flights, and partially good in Svalbard allowing 2 out of 3 planned flights to be carried out. Thus, airborne measurements with the ASIRAS and coincident airborne laser scanner (ALS) have been collected to acquire gridded data over Austfonna ice cap in Svalbard for CryoSat-2 validation, first direct Sentinel-3A underflight over sea ice in the Fram Strait and additionally to repeat some previously flown sea tracks in Fram Strait and the Wandel Sea. Vertical photography was acquired during sea ice flights to support analysis of ASIRAS and ALS observations.

The ASIRAS and ALS instruments worked without any major problems. ASIRAS was only operated in LAM-mode, due to a mal-function of PC2. Comparison of ASIRAS to coincident ALS runway overflights concluded that ASIRAS level-1b processed with the ASIRAS processor version ASIRAS_04_03 shows overall good quality. The ALS data is likewise of high quality with mean difference less than 3 cm and standard deviation less than 10 cm at existing cross-over points. The actual loss of ALS data, due to freezing of moisture on the ALS window in extreme cold conditions (<-25°C) experienced at Station Nord was limited to ferry flights to the designated survey areas.

Preliminary comparisons between CryoSat-2 and ALS data at Austfonna ice cap, proves the concept of using a gridded ALS data set of lines parallel to CryoSat-2 ground tracks in areas with varying topography. First comparisons of Sentinel-3A and ALS also show consistent results, with some unexplained high freeboard values in the Sentinel-3A retracked data potentially originating from off-nadir icebergs.

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APPENDIX

A Operator logs

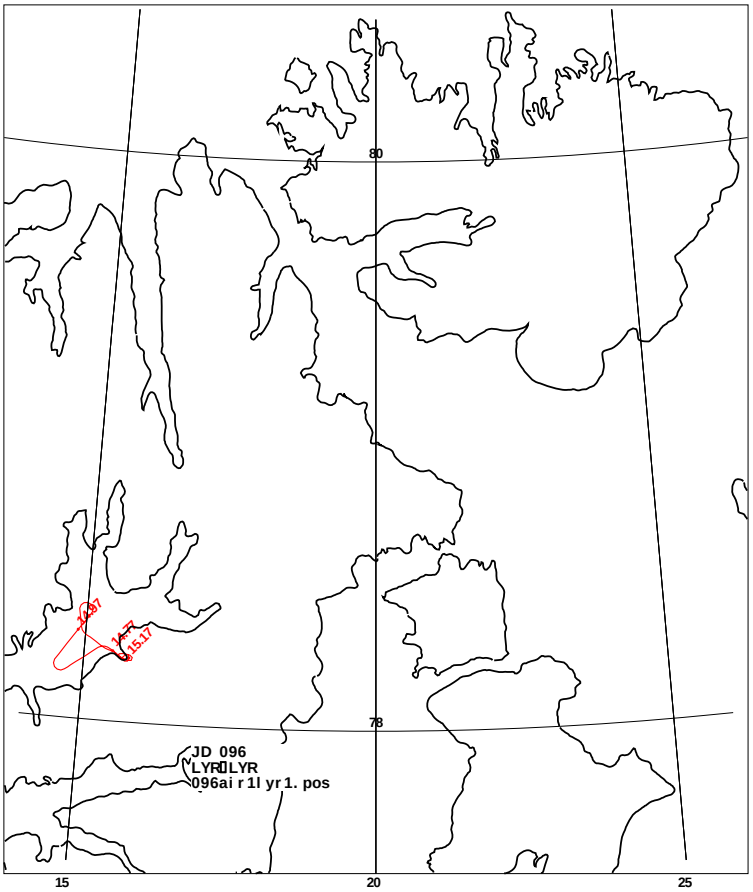
DOY 96, April 5, 2016: Test flight LYR (fjord and building)

ALS-log:

14:45	Ready to Start
14:48	Take -off ? for overflight of fjord and building.
15:09	Building S -> N
15:11	Building W-> E
15:15	Building E -> W, On ground.

ASIRAS-log:

14:46	Taxi for test flight
14:47	Take-off
15:02	PC2 not working



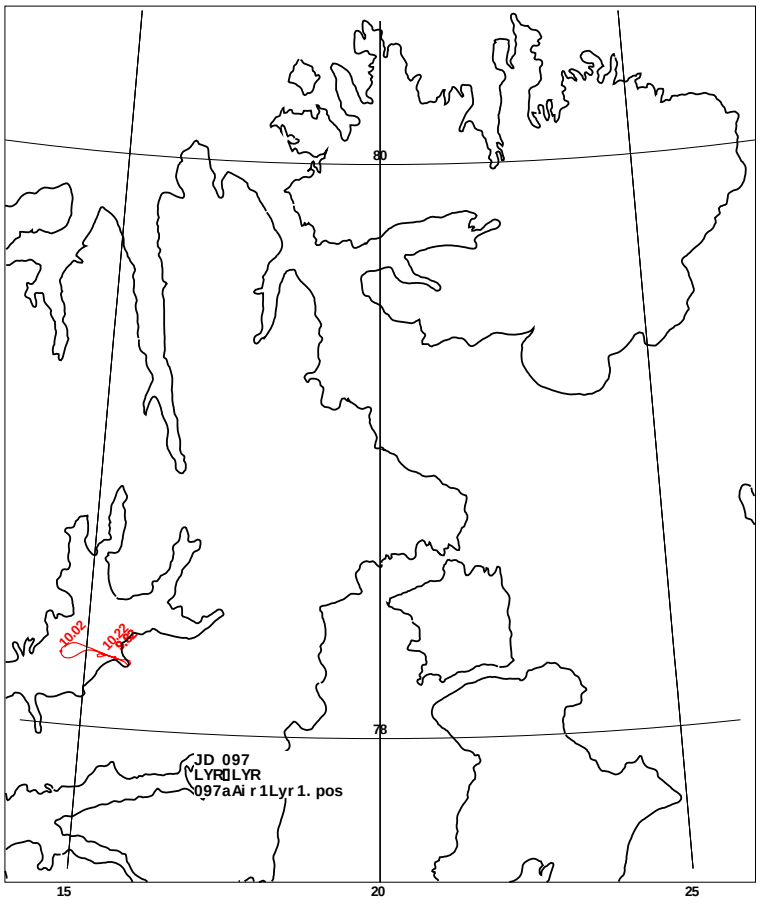
DOY 97a, April 6, 2016: Test flight LYR (fjord and runway)

ALS-log:

09:53	Taxi
09:55	Take off
09:57:30	New scanner file, Asiras ok, Going for runway overflight at ~300 meters.
10:05	1st pass
10:09	2nd pass
10:10	Close scanner file
10:14	On ground

ASIRAS-log:

09:39	Ready for ASIRAS test
09:53	Taxi
09:55	Take off
09:57	ASIRAS started and running new rec.
10:04	1st pass Event 0
10:06	turn for second pass
10:07	2nd pass of runway Event 1
10:08	stopped rec.
10:09	PC1 off
10:14	On ground



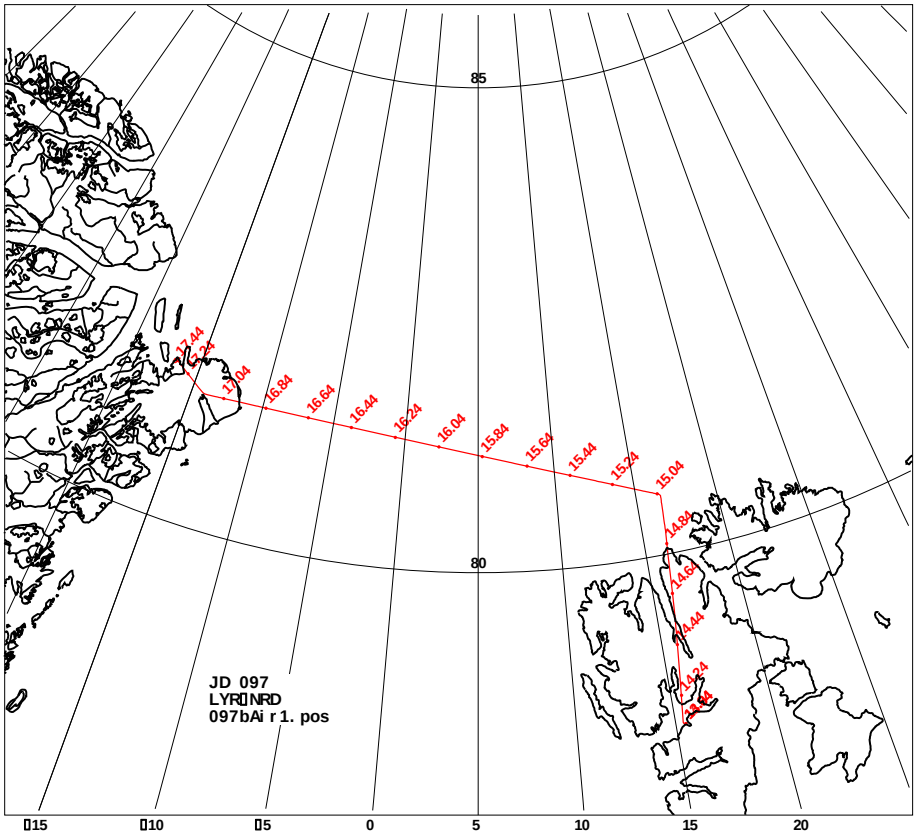
DOY 97b, April 6, 2016: LYR – S3A – STN

ALS-log:

hh:mm	Taxi
hh:mm	Take-off
14:20	Ops. Normal
14:31	uEye started
14:35:57	uEye stopped
14:37:20	uEye started
14:38:40	uEye stopped
14:39:20	uEye started
14:40	uEye started new exp. Setting
14:57:15	uEye started new exp. Setting
15:04:45	Started new scanner file 097_150445.2dd
15:08	Ops. On S3A-S3B little clouds
15:27:50	uEye started new exp. Setting
15:32	at s3b
15:38:00	uEye started new exp. Setting
15:47	Ops. Low clouds but returne on als
15:48	Ops. No clouds
15:51	uEye started new exp. Setting
15:55:10	new scanner file. Wrong sync in 097_155430.2dd, new file 097_155510.2dd
16:03	At s3c
16:14	Ops. Normal
16:23	Ops. Ground fog
16:24	lost echo on scanner
16:27	Echo from clouds
16:29	Climbed 100ft
16:30	Sentinel-3 pass at N 81 24.43, W 04 50.03
16:31	Scanner stopped
16:32	Climbed 100ft
16:33	Climbed 100ft
16:34	at s3d
16:35	uEye stopped
16:43	new scanner file, but logging not started due to clouds
16:56:30	new scanner file for the survey of FIB
16:59	Echo from FIB
17:06	At s3e
17:16	done with FIB
17:18	first overflight and turn
17:21	second overflight
17:24	On ground STN

ASIRAS-log:

14:59	ASIRAS turn on
15:02	cal file A160406_
15:06	started rec.
15:41	clouds no als
16:00	New file 02_1_00
16:20	Low thin layer
16:23	lost als signal
16:27	Climbed 100ft above clouds
16:30	Climbed 100ft above clouds
16:33	Climbed to 420
16:37	Climbed to 480
16:37	uEye stopped
16:44	tested cloud base but had to climb to 540
16:54	New file 03
17:15	stop rec and calb.



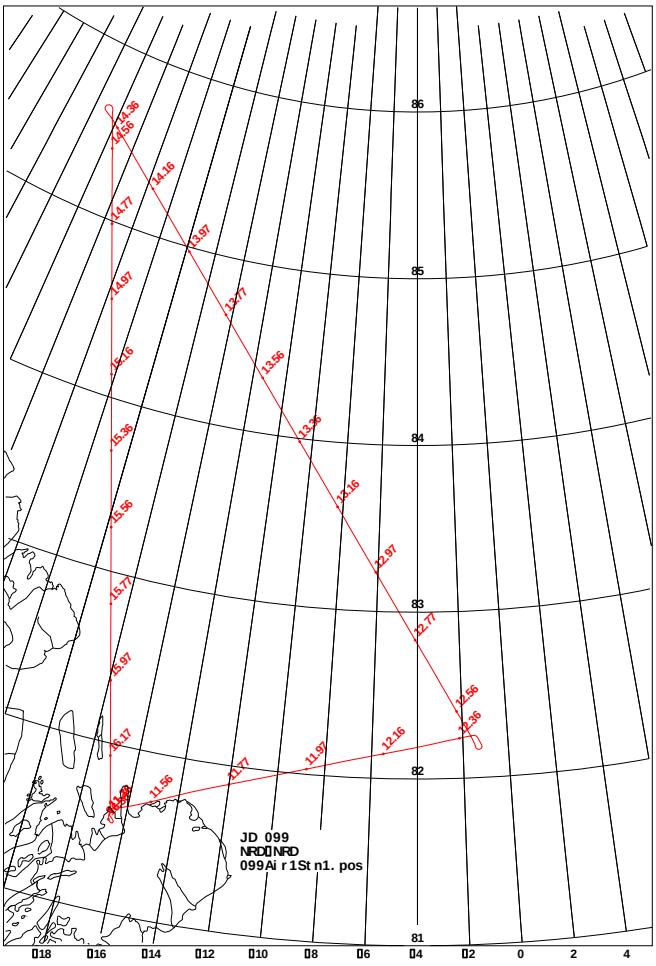
DOY 99, April 8, 2016: STN-F1-F2-STN

ALS-log:

Before take-off	(~-30 deg laser cold had to heat it, the laser is set to last pulse
11:22	Taxi
11:26	Take-off
11:28	Lost scanner echo during the climb, icing on internal window.
11:45	Scanner slowly warming, weak echo
11:47:50	New scanner file, Weak echo about only half the width.
11:52	Lost echo on scanner clouds
11:53	echo back
11:55	uEYE cannot be started
12:00	GoPro on
12:11	Ops. normal good survey conditions the scanner is getting better.
12:23	At F1 and turn for teardrop
12:29	At F1
12:30	Scanner looks better, now about 150m scan
12:40:55	New scanner file (good scanner echo)
13:37:30	New scanner file, notification about sync error
14:23	at F2 and turn for teardrop. Resync. Scanner
14:27:40	New scanner file, no data
14:28:10	New scanner file, file stopped to fast, might have the XO of the teardrop
14:29:15	New scanner file, just after the crossing at f2, missing the XO
15:22:30	New scanner file, the fille 099_152200.2dd started, the right file is 099_152230.2dd
16:03	Fast ice started about 15 min/38 nm out of STN
16:18	1st pass of rwy
16:22	2nd pass of rwy
16:25	crossing the rwy
16:26	stop scanner file
16:28	On ground STN

ASIRAS-log:

11:32	Startup ASIRAS
11:34	New ASIRAS File 00
12:21	F1
12:22	New ASIRAS File 01
13:16	Big ice islands
13:26	New ASIRAS File 02
14:22	F2
14:22	New ASIRAS File 03
15:20	New ASIRAS File 04
16:01	Ok conditions for work on the ice with snowmobile.
16:07	New ASIRAS File 05
16:16	Rwy overflight STN, 1 pass, event 1
16:20	Rwy overflight STN, 2 pass, event 1
16:27	On ground



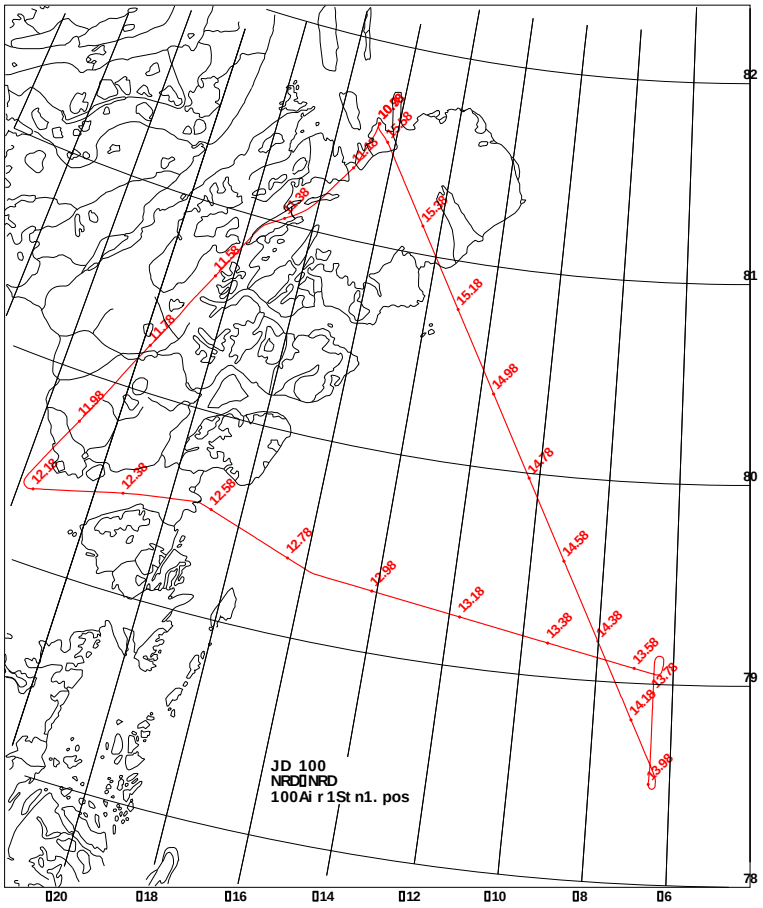
DOY 100, April 9, 2016: STN-79Glac-TOB-ULS-STN

ALS-log:

10:43	GoPro started
10:58	Taxi
11:03	Take-off
11:05:30	New scanner file (using last pulse)
11:07	losing scanner echo, weak signal
11:16	Weak echo, flying high
11:20:00	Logging stopped
12:02:00	New scanner file, weak signal high altitude ice on mirror, only half return.
12:06	scanner ok
12:07	turn for G9
12:18	weak return from half the scanner, icing??
12:23	At G8
12:29	Scanner ok, the icing on the mirror correlates to the change in altitude
12:31	At the front of 79glacier
12:32	At G7
12:49	at TOB
13:02:05	New scanner file
13:37	ULN15 and tune left to tear drop
13:43	at ULN 16
13:50	at UL14
13:55	at ULS16 and turn for teardrop
13:56:55	New scanner file
14:03	at ULS15
14:19	XO of line TOB-ULN15
14:44:05	New scanner file, called 100_1444405.2dd
15:17	front of FIB
15:34	Scanner stopped
15:38	On ground STN

ASIRAS-log:

11:03	Take-off at STN
11:07	Turned on ASIRAS and cal.
11:57	Started record
11:59	Ice edge
12:08	WP G1 79glacier
~12:30	At glacier front
12:53	New file 01
12:56	Fast ice / Drifting ice edge
13:35	ULSN15 -> ULSN16
13:48	ULSF14, event 1, Prevailing wind NE 45deg right of flight direction
13:55	ULS S16
13:56	New ASIRAS File 02
14:58	New ASIRAS file 03
15:15	Flade isblink
15:30	Shut down ASIRAS



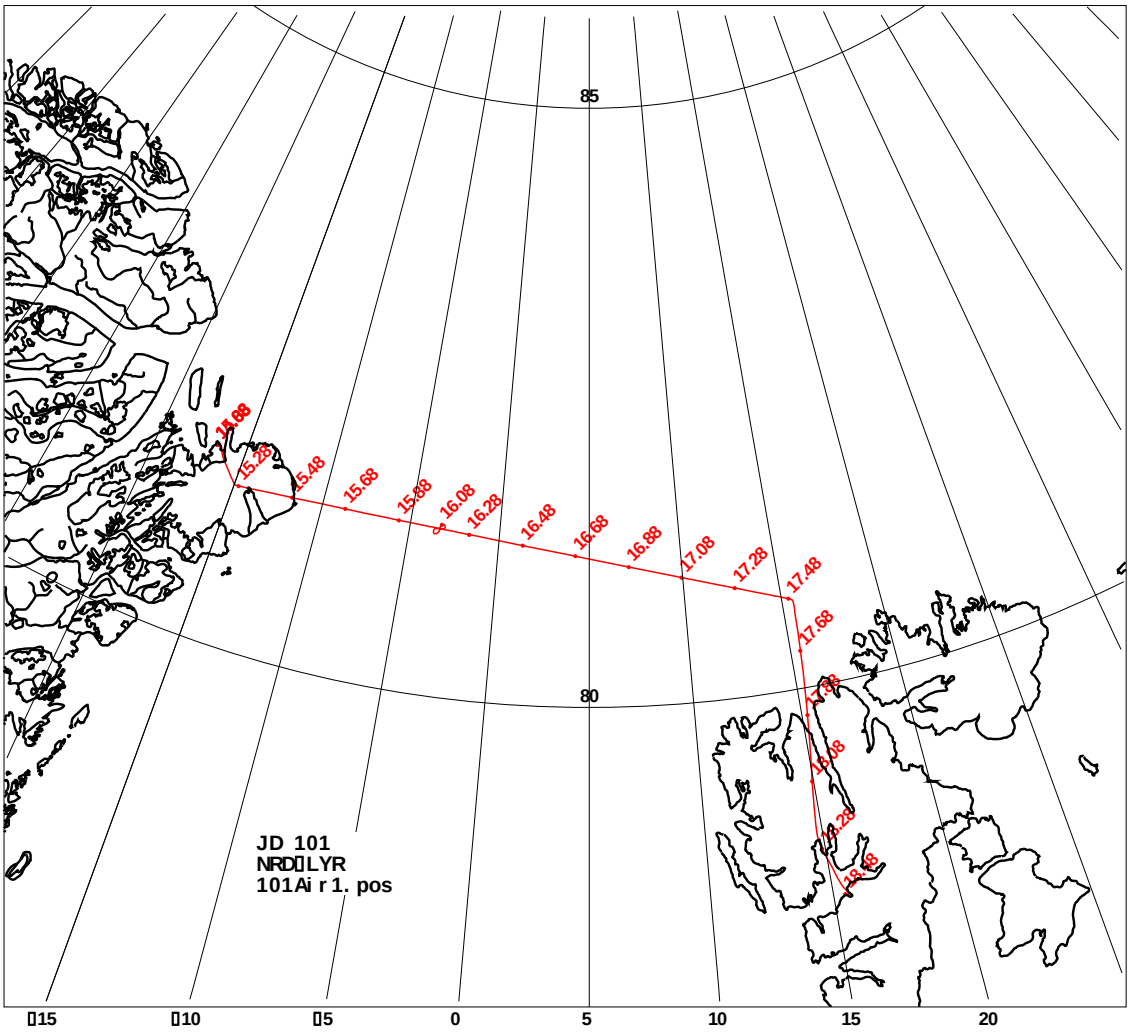
DOY 101, April 10, 2016: STN-S3A– LYR

ALS-Log:

14:21	GoPro turn on
15:01	Taxi-off
15:05:55	New scanner file, scanner set to last pulse
15:08	icing in scanner only half the scan
15:15	At S3F
15:17	Strong winds at FIB, drifting snow. Almost no scanner echo
15:23	Echo back only half width
15:29	off FIB
15:30	scanner width increasing
15:47	at S3G
15:59:30	New scanner file
16:02	teardrop right
16:05	XO of track
16:09	Back on track and XO of XO
16:27	S3 passing, at 81 20.24N 01 07.00 E
16:58	At S3I
16:59:50	New scanner file
17:22	Low clouds, ok echo
17:28	Break line and heading for LYR, about 3 min from S3J
17:28	Stopping Scanner
17:41	GoPro stopped
18:27	On Ground LYR

ASIRAS-log:

15:07	Turned on ASIRAS and Cal
15:08	Started log 00
16:00	New ASIRAS file 01 , Tear drop
16:27	S3A passage time
17:00	New ASIRAS file 02
17:26	Stop file and cal
18:28	Landed, On ground LYR.



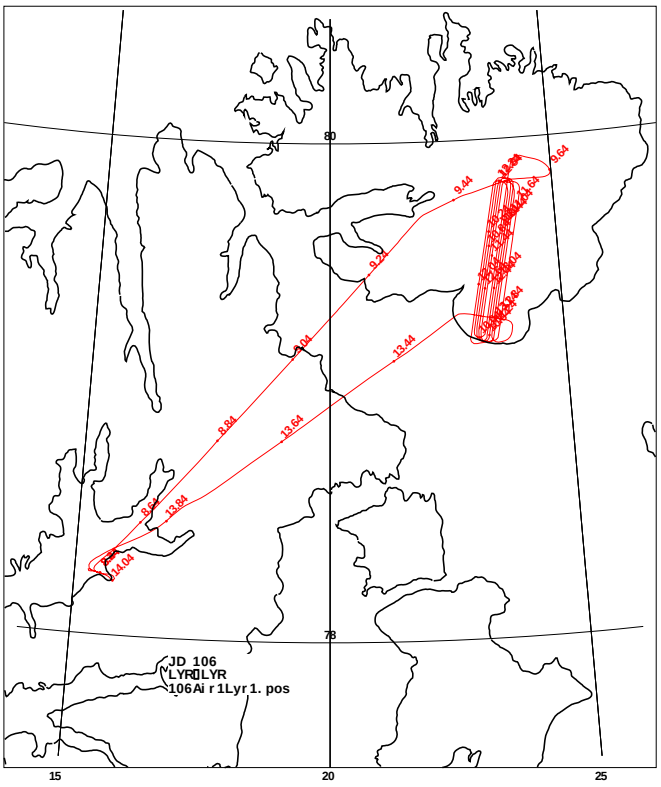
DOY 106, April 15, 2016: LYR-Austfonna-LYR

ALS-log:

08:27	Taxi
08:29	Take off
09:23	Reached Austfonna. Cloudy.
09:26	New scanner file 106_092600.2dd
09:26-09:46	Many clouds in the area. When flying along the crossing (W-E) line only very little LiDAR could be collected. It was decided to try a different CS track. Aim for CS26.
09:46	Free of clouds on CS26N- CS26S. But Northern part of the planned tracks are completely cloud covered.
10:02	New scanner file 106_100230.2dd
10:04	At L11s26
10:19	Break line due to clouds
10:22	On track R5n26-R5s26
10:41	On track L9s26- L9n26
10:58	New scanner file 106_105800.2dd
11:00	On track R9s26- R9n26
11:18	On track R5s26- R5n26
11:37	On track R13n26- R13s26
11:54	New scanner file 106_115400.2dd
	No more planned tracks as WPs. Decide to densify grid to 1km spacing. The following lines were flown as 1000m west of other tracks.
11:57	Start of track : 1000m west of L11 ('L13')
12:15	Start of track : 1000m west of R5 ('R3')
12:33	Start of track : 1000m west of L5 ('L3')
12:51	New scanner file 106_125130.2dd
12:53	Start of track : 1000m west of L9 ('L7')
13:10-13:18	Crossing all lines
13:54	New scanner file 106_135400.2dd two runway overflights
14:08	Landing

ASIRAS-log:

08:28	Take off
08:43	Cal
09:15	Cal
09:17	Started ASIRAS file 00_1_00
09:18	At 720 m alt.
09:24	At 300 m alt.
09:29	Low clouds
09:37	Changing plans for flight due to clouds. Going for the CS2 pass at the 26 of April
09:40	At new line
09:50	ops. Normal
10:00	turn and start/stop file 01_1_00, then started file 02_1_00
10:01	Northbound line
10:17	Turn
10:36	next line
10:39	on line and ice
10:55	turn
10:55	new file 03_1_00
11:03	turn clouds
11:32	turn end of line
11:51	turn and new file 04_1_00
12:11	turn clouds at the north dome of Austfonna
12:14	on line southbound
12:30	end of line
12:34	on line north
12:47	turn for south bound
12:48	new file *05*_1_00
12:50	on line south
13:06	turn left for cross of all lines
13:15	end of grid xo
13:16	stop record
13:53	started asiras for runway overflight, new file 06_1_00
13:57	1st pass event 0
14:01	2nd pass event 1
14:03	stopped
14:03	cal



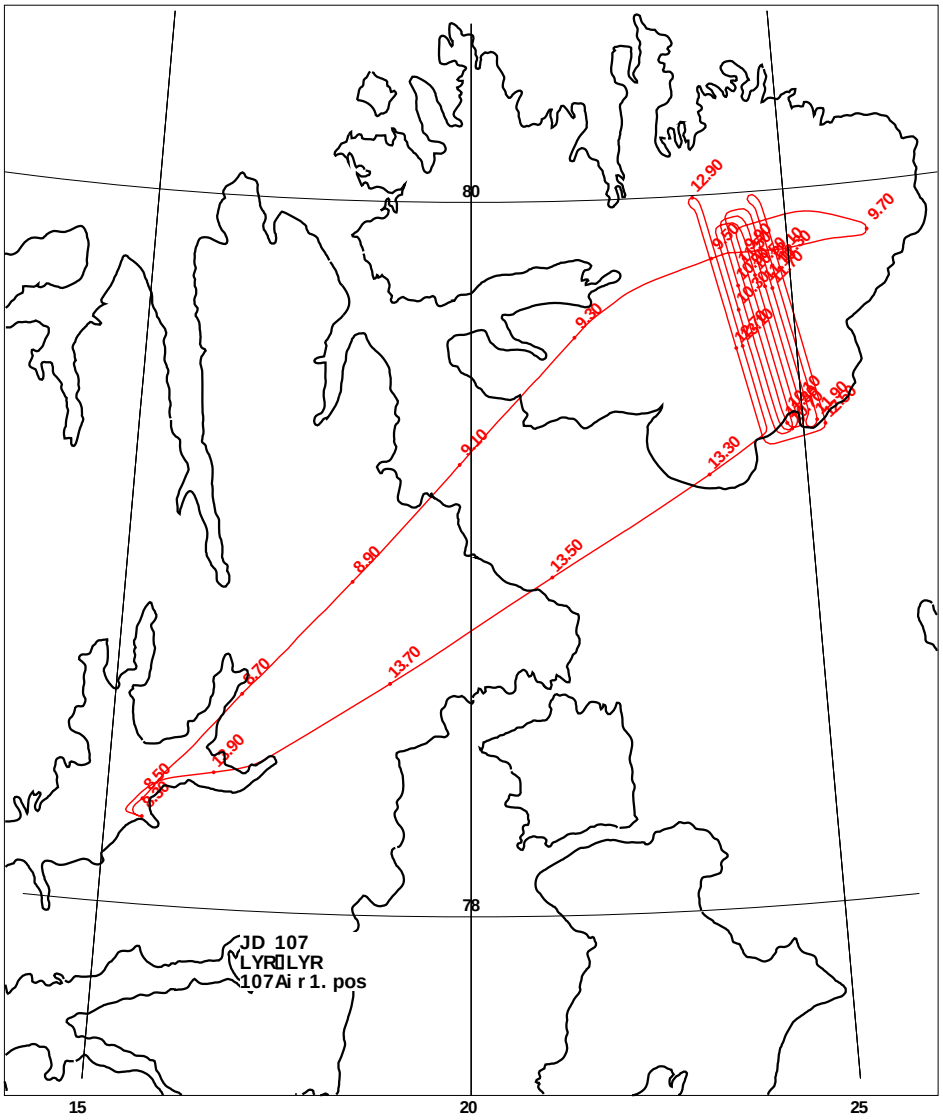
DOY 107, April 16, 2016. LYR-Austfonna-LYR

ALS-log:

08:24	Taxi
08:26	Take off
09:22	At ETON1. Cloudy.
09:23	New scanner file: 107_092330.2dd. No clouds.
09:47	Clouds. We will have to skip the northern-most part of all tracks.
09:50	On track CS19n-CS19s
10:09	On track L13s19- L13n19
10:23	Break off line
10:25	New scanner file: 107_102500.2dd
10:27	On track R5n19- R5s19
10:43	On track L9s19- L9n19
10:59	Break off line
11:01	On track R9n19- R9s19
11:15	Break off line
11:16	New scanner file: 107_111630.2dd
12:11	New scanner file: 107_121100.2dd
12:13-	Without WPs: on tracks 'R21n19-R21s19' followed by 'L21s19-L21n19'
1402	Landing

ASIRAS-log:

08:26	Take-off
09:04	cal
09:09	cal
09:10	Record without return, altitude?
09:14	rec stop
09:16	cal
09:17	start new file 01_1_00
09:39	turn for grid around CS2 April 19
09:50	at CS2 line
10:04	turn at coast
10:07	on line northbound
10:22	new file 02_1_00
11:14	turn new file 03_1_00
12:08	turn new file 04_1_00
13:10	turn and end of rec
13:10	cal and closing down



B Coordinates of GPS base stations

All processing of reference stations are done by the online services at http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos.

Date	DOY	Reference	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height (m)
05-04-2017	096	LYR	78° 14′ 51.54631′′	15° 29′ 31.23559′′	50.197
06-04-2017	097a	LYR	78° 14′ 51.55234′′	15° 29′ 31.31248′′	50.237
08-04-2017	099	STN	81° 36′ 02.38057′′	-16° 39′ 42.25359′′	66.266
09-04-2017	100	STN	81° 35′ 46.52426′′	-16° 39′ 28.76166′′	62.020
15-04-2017	106	LYR	78° 14′ 46.55145′′	15° 30′ 09.01729′′	54.429
16-04-2017	107	LYR	78° 14′ 46.56476′′	-15° 30′ 08.95578′′	54.412

C Overview of acquired ALS data

Date	DOY	File name	Start time (dechr)	Stop time (dechr)	Calib. Angles (pitch, roll, heading)	dt (sec)
05-04-2016	96	96_145700.2dd	14.94506	15.26464	-1.72, -0.07, 0.0	-9
06-04-2016	97	097_095730.2dd	09.95855	10.17761	-1.67, -0.09, 0.0	2
		097_150445.2dd	15.07930	15.76766		0
		097_155430.2dd	15.90436			0
		097_155510.2dd	15.91927	16.52252		0
		097_164430.2dd				0
		097_165630.2dd	16.94183	17.36307		0
08-04-2016	99	099_114750.2dd	11.79671	12.48510	-1.67, -0.07, 0.0	0
		099_124055.2dd	12.68186	13.37027		0
		099_133730.2dd	13.62464	14.31308		0
		099_142740.2dd				
		099_142810.2dd	14.46923	14.47255		0
		099_142915.2dd	14.48744	15.17588		-1
		099_152200.2dd				
		099_152230.2dd	15.37495	16.06341		-1
09-04-2016	100	100_110530.2dd	11.09154	11.35013	-1.72, -0.07, 0.0	0
		100_120200.2dd	12.03346	12.72182		0
		100_130205.2dd	13.03486	13.72329		0
		100_135655.2dd	13.94870	14.63712		0
		100_1444405.2dd	14.73486	15.42329		0
10-04-2016	101	101_150555.2dd	15.09852	15.78693	-1.72, -0.07, 0.0	0
		101_155930.2dd	15.99136	16.67981		0
		101_165950.2dd	16.99735	17.47713		0
15-04-2016	106	106_092600.2dd	09.43339	10.02698	-1.72, -0.07, 0.0	0
		106_100230.2dd	10.04177	10.73011		0
		106_105800.2dd	10.96677	11.65510		0
		106_115400.2dd	11.89981	12.58814		0
		106_125130.2dd	12.85844	13.30773		0
		106_135400.2dd	13.90006	14.07921		0
16-04-2016	107	107_092330.2dd	09.39178	10.08011	-1.84, -0.08, 0.0	0
		107_102500.2dd	10.41677	11.10509		0
		107_111630.2dd	11.27512	11.96344		0
		107_121100.2dd	12.18345	12.87178		0

D Overview of acquired ASIRAS log-files

Date	File name	Start time (UTC)	End time (UTC)	Range window (m)	# Pulses
05-04-2016	A160405_00.log	Problems with PC2		360.00	153199
	A160405_01.log			360.00	34866
06-04-2016	A160406_00.log	09:58:14	10:10:23	360.00	1822490
	A160406_01.log	15:07:43	16:01:40	90.00	8092449
	A160406_02.log	16:01:45	16:56:18	90.00	8182446
	A160406_03.log	16:56:22	17:16:34	90.00	3029980
08-04-2016	A160408_00.log	11:36:07	12:23:54	90.00	7167456
	A160408_01.log	12:23:59	13:28:40	90.00	9702442
	A160408_02.log	13:28:44	14:23:37	90.00	8232450
	A160408_03.log	14:23:41	15:22:34	90.00	8832446
	A160408_04.log	15:22:37	16:09:31	90.00	7034957
	A160408_05.log	16:09:34	16:23:19	90.00	2062487
09-04-2016	A160409_00.log	11:59:16	12:55:17	90.00	8402446
	A160409_01.log	12:55:21	13:58:32	90.00	9477436
	A160409_02.log	13:58:36	15:00:13	90.00	9242438
	A160409_03.log	15:00:16	15:32:27	90.00	4827467
10-04-2016	A160410_00.log	15:09:59	16:02:10	90.00	7827451
	A160410_01.log	16:02:14	17:00:19	90.00	8712443
	A160410_02.log	17:00:22	17:27:52	90.00	4124973
15-04-2016	A160415_00.log	09:18:57	10:01:31	90.00	6384958
	A160415_01.log	10:01:37	10:01:46	90.00	22500
	A160415_02.log	10:01:59	10:57:27	90.00	8319944
	A160415_03.log	10:57:30	11:52:58	90.00	8319943
	A160415_04.log	11:53:01	12:50:50	90.00	8672442
	A160415_05.log	12:50:53	13:18:20	90.00	4117473
	A160415_06.log	13:55:09	14:04:39	90.00	1424991
16-04-2016	A160416_00.log	09:12:34	09:16:25	90.00	577497
	A160416_01.log	09:19:17	10:24:03	90.00	9714935
	A160416_02.log	10:24:07	11:16:13	90.00	7814948
	A160416_03.log	11:16:18	12:10:47	90.00	8172445
	A160416_04.log	12:10:50	13:12:33	90.00	9257437

E File name convention

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

ASIRAS:
AS30AXX_ASIWL1BNNNN_SSSSSSSSSSSSSSS_PPPPPPPPPPPPPPP_0001.DBL

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

GPS
GPS_ANT_VER_SSSSSSSSSSSSSS-PPPPPP_0001.DAT

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

Inertial Navigation System (INS)
INS_ SSSSSSSSSSSSSS-PPPPPP_0001.DAT

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

Airborne laser scanner (ALS) full resolution
ALS_SSSSSSSSSSSSSS-PPPPPP.XXX

SSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS
XXX	Data format which is either sbi (binary) or nc (netcdf4)

F 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).

	File	Size [MB]
96	GPS_R_20160405T144559_151837_0001.DBL	0.1
097a	GPS_R_20160406T093656_101927_0001.DBL	0.2
097b	GPS_R_20160406T134950_172958_0001.DBL	0.8
099	GPS_R_20160408T110941_163200_0001.DBL	1.2
100	GPS_R_20160409T104614_154300_0001.DBL	1.0
101	GPS_R_20160410T144015_183129_0001.DBL	0.8
106	GPS_R_20160415T081412_140915_0001.DBL	1.3
107	GPS_R_20160416T081752_140236_0001.DBL	1.2

G 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	File	Size [MB]
05-04-2016	INS_20160405T144536_151754_0001.DBL	3
06-04-2016	INS_20160406T093718_101756_0001.DBL	4
06-04-2016	INS_20160406T135146_172748_0001.DBL	22
08-04-2016	INS_20160408T110936_163110_0001.DBL	33
09-04-2016	INS_20160409T104612_154203_0001.DBL	31
10-04-2016	INS_20160410T144227_183013_0001.DBL	24
15-04-2016	INS_20160415T081348_140759_0001.DBL	37
16-04-2016	INS_20160416T081724_140300_0001.DBL	36

H Data format ALS - DTU Space binary (*.sbi)

The ALS files are provided in an 18-bit little-endian binary format. The bit-string is read according to the syntax given in the Table below. In python the data can be read by using the script provided in the text-box below.

Value	Byte Type	Standard size	Scaling factor
UTC time [hours]	Int	4	10^{-7}
Latitude [deg N]	Int	4	10^{-7}
Longitude [deg E]	Int	4	10^{-7}
Elevation [m]	Int	4	10^{-3}
Amplitude	signed char	1	1
Scan no. in scanline	unsigned char	1	1

```
dt =np.dtype([('tid', '<i'), ('lat', 'i'), ('lon','i'),('hoj','i'), ('s1','b'),('s2','B')])

data = np.fromfile(ifile, dtype=dt)

data['tid'] = data['tid'] *1.0E-7

data['lat'] = data['lat'] *1.0E-7

data['lon'] = data['lon'] *1.0E-7

data['hoj'] = data['hoj'] *1.0E-3
```

I Processed ALS data

Date	DOY	Final file:	File size (MB)
05-04-2016	96	ALS_20160405T145633_151543.sbi	47
06-04-2016	97a	ALS_20160406T095732_101041.sbi	22
06-04-2016	97b	ALS_20160406T150445_155400.sbi	261
		ALS_20160406T155415_155415.sbi	0.003
		ALS_20160406T155509_162442.sbi	214
		ALS_20160406T165822_172147.sbi	145
08-04-2016	99	ALS_20160408T114748_124032.sbi	185
		ALS_20160408T124054_133656.sbi	396
		ALS_20160408T133728_142503.sbi	383
		ALS_20160408T142809_142821.sbi	2
		ALS_20160408T142913_152138.sbi	425
		ALS_20160408T152228_162601.sbi	515
09-04-2016	100	ALS_20160409T110529_112058.sbi	18
		ALS_20160409T120200_130138.sbi	383
		ALS_20160409T130205_135633.sbi	419
		ALS_20160409T135655_144340.sbi	352
		ALS_20160409T144405_153402.sbi	381
10-04-2016	101	ALS_20160410T150554_155910.sbi	148
		ALS_20160410T155928_165925.sbi	382
		ALS_20160410T165950_172837.sbi	182
15-04-2016	106	ALS_20160415T092600_100137.nc	69
		ALS_20160415T100230_105729.nc	160
		ALS_20160415T105914_115327.nc	175
		ALS_20160415T115359_124947.nc	176
		ALS_20160415T125136_131820.nc	89
		ALS_20160415T135400_140445.nc	17
16-04-2016	107	ALS_20160416T092330_102336.nc	162
		ALS_20160416T102602_111552.nc	167
		ALS_20160416T111630_120958.nc	183
		ALS_20160416T121301_131316.nc	199

J Data format vertical images

Approximate time and position of the vertical camera when a picture is taken is delivered in windows ASCII format as described in Table below and all individual pictures are in JPEG format. Each ASCII line gives the filename, time and position for the named picture. If no DGPS data is available, the time and position is replaced with the string “No position available”.

Identifier	Description	Unit
1	JPEG filename	
2	Decimal hours	hour
3	Latitude (WGS-84)	deg
4	Longitude	deg
5	Geodetic ellipsoidal height	m
6	Newline characters "\r \n"	

K Time-tagged and geo-located vertical images

The following time-tagged and geo-located images are available from the GoPro or uEye cameras.

ASCII file	Date of acquisition	File name of zipped images	File size (MB)
PIX_uEye_20160406.pos	06-04-2016	PIX_uEye_20160406T143114-145959.zip	1,075
		PIX_uEye_20160406T150000-155959.zip	1,820
		PIX_uEye_20160406T160000-163600.zip	2,244
PIX_GoPro_20160408.pos	08-04-2016	PIX_GoPro_20160408T120032-123330.zip	1,869
		PIX_GoPro_20160408T123333-130648.zip	1,947
		PIX_GoPro_20160408T130651-134006.zip	2,043
		PIX_GoPro_20160408T134009-141324.zip	2,005
		PIX_GoPro_20160408T141327-144642.zip	2,072
		PIX_GoPro_20160408T144645-151959.zip	2,186
		PIX_GoPro_20160408T152003-155120.zip	1,694
		PIX_GoPro_20160408T155123-162438.zip	1,644
		PIX_GoPro_20160408T162441-163039.zip	283
PIX_GoPro_20160409.pos	09-04-2016	PIX_GoPro_20160409T105911-111632.zip	882
		PIX_GoPro_20160409T111635-114951.zip	1,795
		PIX_GoPro_20160409T114954-122309.zip	1,874
		PIX_GoPro_20160409T122312-125627.zip	1,728
		PIX_GoPro_20160409T125630-132945.zip	2,082
		PIX_GoPro_20160409T132948-140303.zip	1,808
		PIX_GoPro_20160409T140306-143621.zip	1,962
		PIX_GoPro_20160409T143624-145642.zip	1,314
		PIX_GoPro_20160409T145644-153000.zip	1,857
		PIX_GoPro_20160409T153002-154142.zip	619
PIX_GoPro_20160410.pos	10-04-2016	PIX_GoPro_20160410T150324-152858.zip	1,289
		PIX_GoPro_20160410T152859-160216.zip	1,964
		PIX_GoPro_20160410T160217-160439.zip	137
		PIX_GoPro_20160410T163535-170852.zip	1,816
		PIX_GoPro_20160410T170853-173826.zip	1,437

L 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)
06-04-2016	97	AS6OA00_ASIWL1B0403201604 06T095814_201604 06T101023_0001.DBL	30
		AS6OA01_ASIWL1B0403201604 06T150743_201604 06T160140_0001.DBL	33
		AS6OA02_ASIWL1B0403201604 06T160145_201604 06T165618_0001.DBL	90
		AS6OA03_ASIWL1B0403201604 06T165622_201604 06T171634_0001.DBL	39
08-04-2016	99	AS6OA00_ASIWL1B0403201604 08T113607_201604 08T122354_0001.DBL	98
		AS6OA01_ASIWL1B0403201604 08T122359_201604 08T132840_0001.DBL	131
		AS6OA02_ASIWL1B0403201604 08T132844_201604 08T142337_0001.DBL	96
		AS6OA03_ASIWL1B0403201604 08T142341_201604 08T152234_0001.DBL	113
		AS6OA04_ASIWL1B0403201604 08T152237_201604 08T160931_0001.DBL	91
		AS6OA05_ASIWL1B0403201604 08T160934_201604 08T162319_0001.DBL	26
09-04-2016	100	AS6OA00_ASIWL1B0403201604 09T115916_201604 09T125517_0001.DBL	100
		AS6OA01_ASIWL1B0403201604 09T125521_201604 09T135832_0001.DBL	118
		AS6OA02_ASIWL1B0403201604 09T135836_201604 09T150013_0001.DBL	108
		AS6OA03_ASIWL1B0403201604 09T150016_201604 09T153227_0001.DBL	60
10-04-2016	101	AS6OA00_ASIWL1B0403201604 10T150959_201604 10T160210_0001.DBL	57
		AS6OA01_ASIWL1B0403201604 10T160214_201604 10T170019_0001.DBL	49
		AS6OA02_ASIWL1B0403201604 10T170022_201604 10T172752_0001.DBL	52

Continued on next page

Date	DOY	File name	Size (MB)
15-04-2016	106	AS6OA00_ASIWL1B040320160415T091857_20160415T100131_0001.DBL	70
		AS6OA01_ASIWL1B040320160415T100137_20160415T100146_0001.DBL	0.3
		AS6OA02_ASIWL1B040320160415T100159_20160415T105727_0001.DBL	100
		AS6OA03_ASIWL1B040320160415T105730_20160415T115258_0001.DBL	100
		AS6OA04_ASIWL1B040320160415T115301_20160415T125050_0001.DBL	102
		AS6OA05_ASIWL1B040320160415T125053_20160415T131820_0001.DBL	51
		AS6OA06_ASIWL1B040320160415T135509_20160415T140439_0001.DBL	18
16-04-2016	107	AS6OA00_ASIWL1B040320160416T091234_20160416T091625_0001.DBL	5
		AS6OA01_ASIWL1B040320160416T091917_20160416T102403_0001.DBL	120
		AS6OA02_ASIWL1B040320160416T102407_20160416T111613_0001.DBL	98
		AS6OA03_ASIWL1B040320160416T111618_20160416T121047_0001.DBL	102
		AS6OA04_ASIWL1B040320160416T121050_20160416T131233_0001.DBL	113

M Final ASIRAS profiles

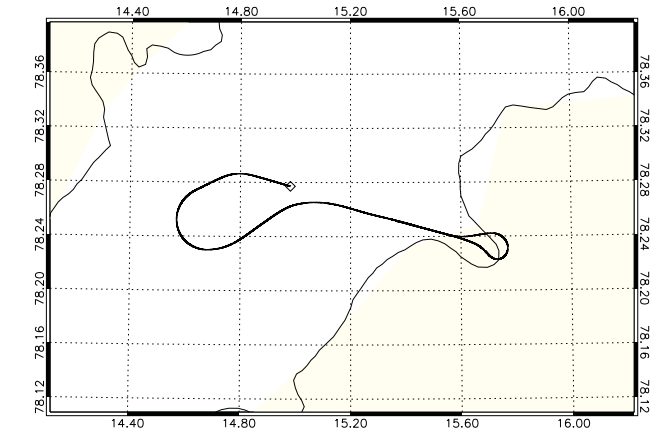
Following plots show all processed ASIRAS profiles using the OCOG retracker. Each profile plot consists of four parts:

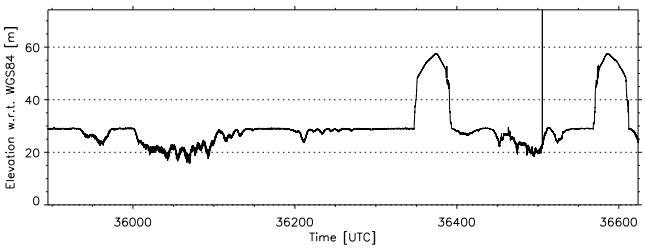
1. Header composed of daily profile number and the date and a sub-header with the filename.
2. Geographical plot of the profile (diamond indicates the start of the profile).
3. Rough indication of the heights as determined with the OCOG retracker plotted versus time of day in seconds.
4. Info box with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

A160406_00

AS60A00_ASIWL1B0403201604O6T095814_20160406T101023_0001.DBL

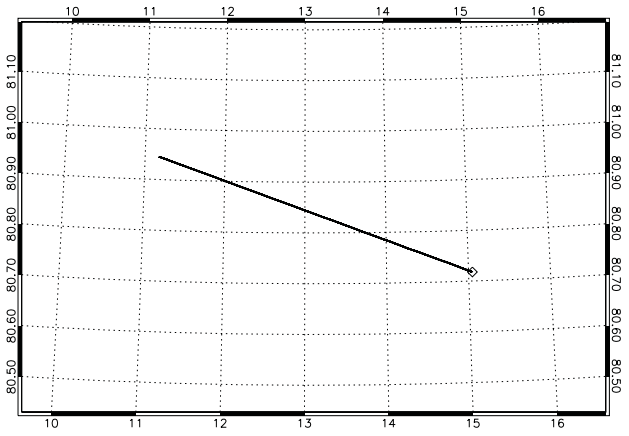


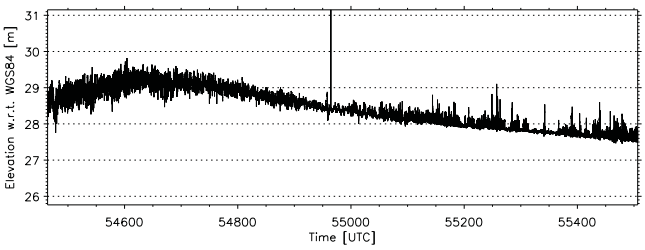


Date	2016-04-06	**Instrument Mode**	Adv. Low Altitude
Start Time	09:58:15 (35895)	**Aircraft**	BAS Twin Otter
Stop Time	10:10:23 (36623)	**Retracker**	OCOG
Distance	52.485 km	**INS Resolution**	50 Hz
Duration	00 h 12 m 09 s	**Processor Version**	0403

A160406_01

AS60A01_ASIWL1B0403201604O6T150743_20160406T160140_0001.DBL

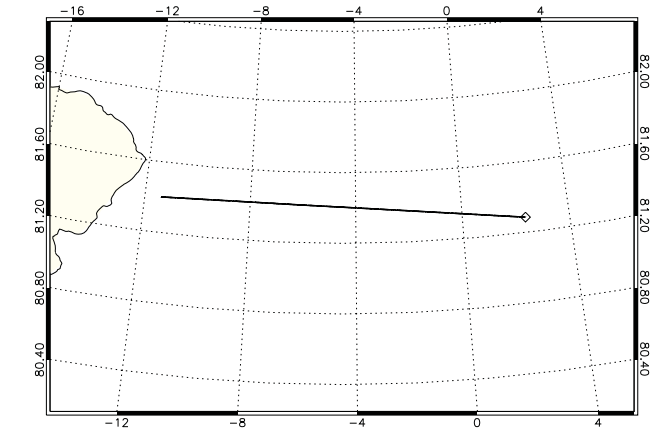


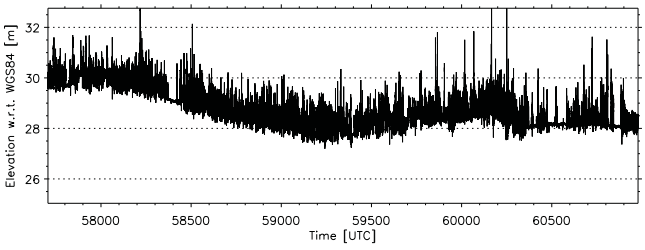


Date	2016-04-06	**Instrument Mode**	Adv. Low Altitude
Start Time	15:07:44 (54464)	**Aircraft**	BAS Twin Otter
Stop Time	15:25:06 (55506)	**Retracker**	OCOG
Distance	73.097 km	**INS Resolution**	50 Hz
Duration	00 h 17 m 23 s	**Processor Version**	0403

A160406_02

AS60A02_ASIWL1B0403201604O6T160145_20160406T165618_0001.DBL

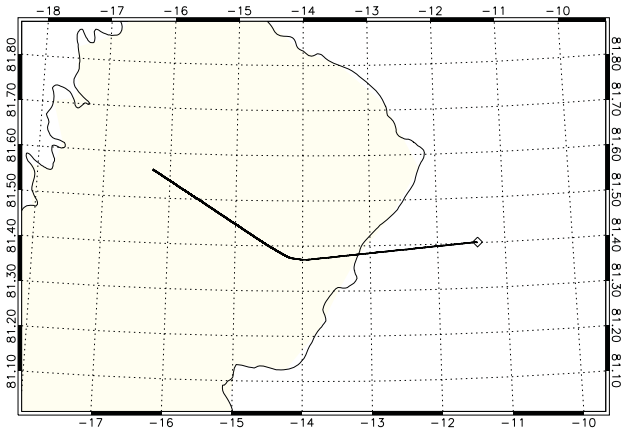


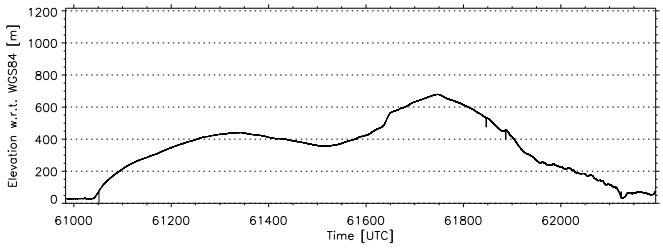


Date	2016-04-06	**Instrument Mode**	Adv. Low Altitude
Start Time	16:01:46 (57706)	**Aircraft**	BAS Twin Otter
Stop Time	16:56:18 (60978)	**Retracker**	OCOG
Distance	230.027 km	**INS Resolution**	50 Hz
Duration	00 h 54 m 32 s	**Processor Version**	0403

A160406_03

AS60A03_ASIWL1B0403201604O6T165622_20160406T171634_0001.DBL

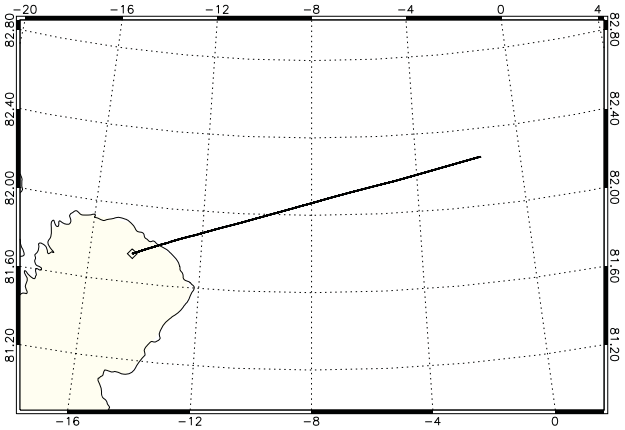


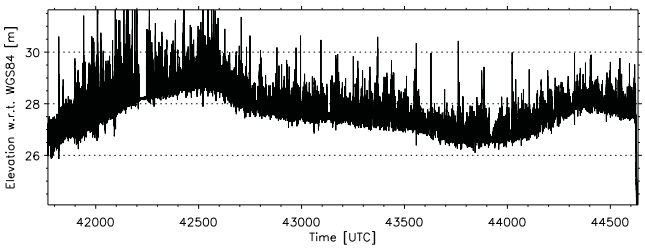


Date	2016-04-06	**Instrument Mode**	Adv. Low Altitude
Start Time	16:56:23 (60983)	**Aircraft**	BAS Twin Otter
Stop Time	17:16:34 (62194)	**Retracker**	OCOG
Distance	86.816 km	**INS Resolution**	50 Hz
Duration	00 h 20 m 12 s	**Processor Version**	0403

A160408_00

AS60A00_ASIWL1B040320160408T113607_20160408T122354_0001.DBL

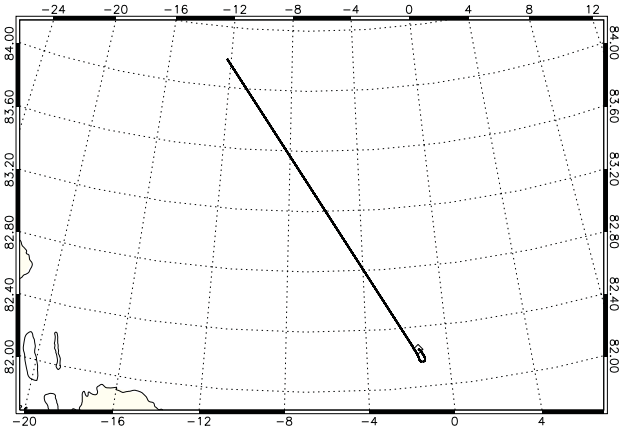


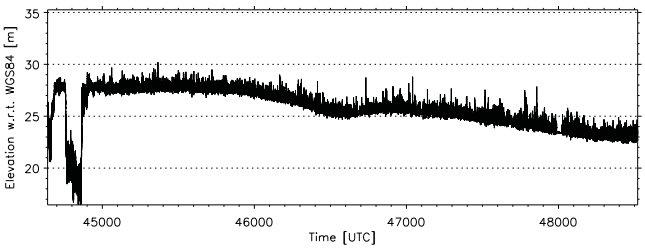


Date	2016-04-08	Instrument Mode	Adv. Low Altitude
Start Time	11:36:08 (41768)	Aircraft	BAS Twin Otter
Stop Time	12:23:54 (44634)	Retracker	OCOG
Distance	208.234 km	INS Resolution	50 Hz
Duration	00 h 47 m 47 s	Processor Version	0403

A160408_01

AS60A01_ASIWL1B040320160408T122359_20160408T132840_0001.DBL

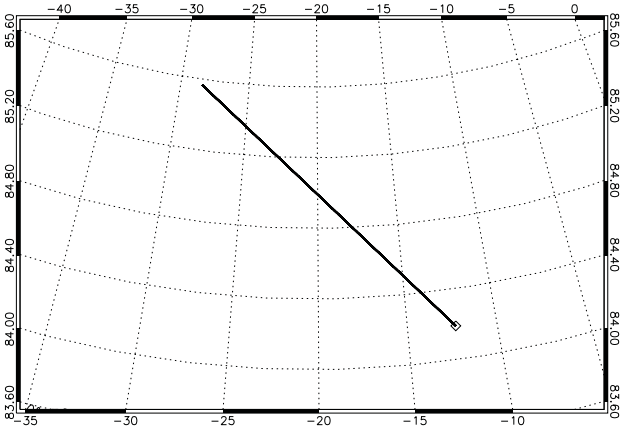


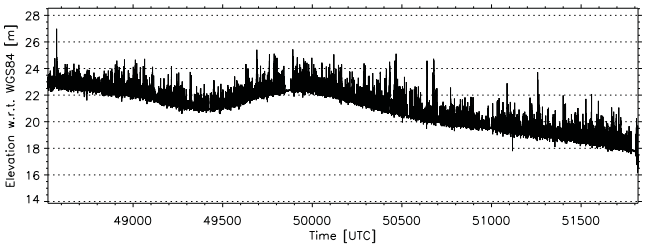


Date	2016-04-08	Instrument Mode	Adv. Low Altitude
Start Time	12:24:00 (44640)	Aircraft	BAS Twin Otter
Stop Time	13:28:40 (48520)	Retracker	OCOG
Distance	279.094 km	INS Resolution	50 Hz
Duration	01 h 04 m 41 s	Processor Version	0403

A160408_02

AS60A02_ASIWL1B040320160408T132844_20160408T142337_0001.DBL

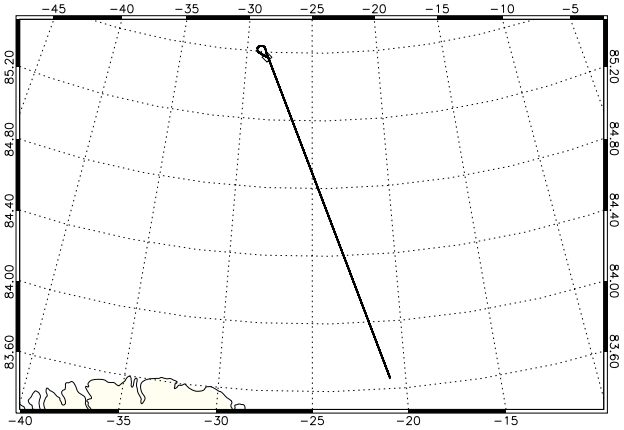


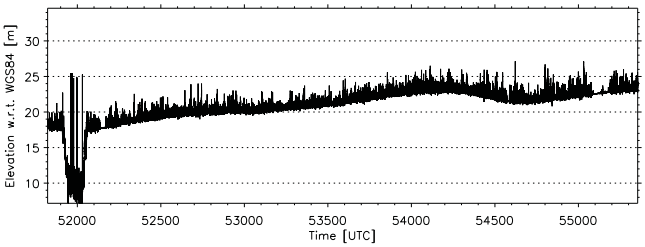


Date	2016-04-08	Instrument Mode	Adv. Low Altitude
Start Time	13:28:45 (48525)	Aircraft	BAS Twin Otter
Stop Time	14:23:37 (51817)	Retracker	OCOG
Distance	220.286 km	INS Resolution	50 Hz
Duration	00 h 54 m 53 s	Processor Version	0403

A160408_03

AS60A03_ASIWL1B040320160408T142341_20160408T152234_0001.DBL

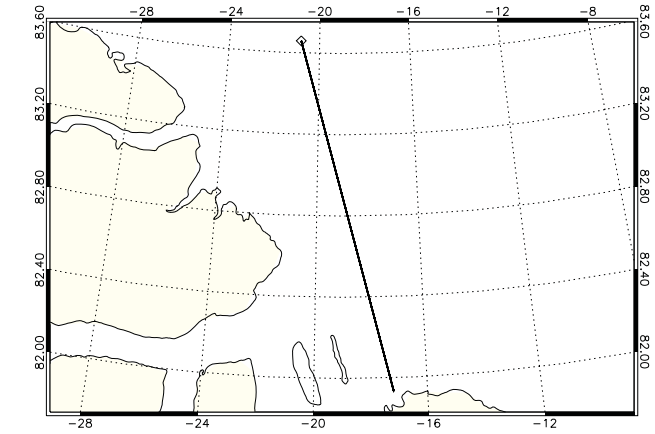


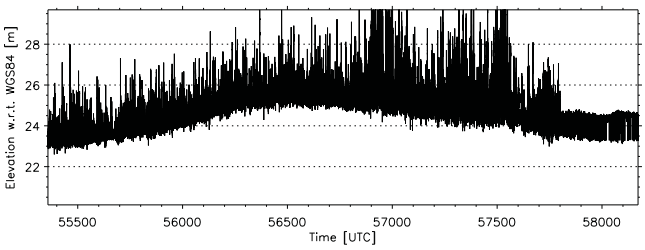


Date	2016-04-08	Instrument Mode	Adv. Low Altitude
Start Time	14:23:42 (51822)	Aircraft	BAS Twin Otter
Stop Time	15:22:34 (55354)	Retracker	OCOG
Distance	247.773 km	INS Resolution	50 Hz
Duration	00 h 58 m 53 s	Processor Version	0403

A160408_04

AS60A04_ASIWL1B040320160408T152237_20160408T160931_0001.DBL

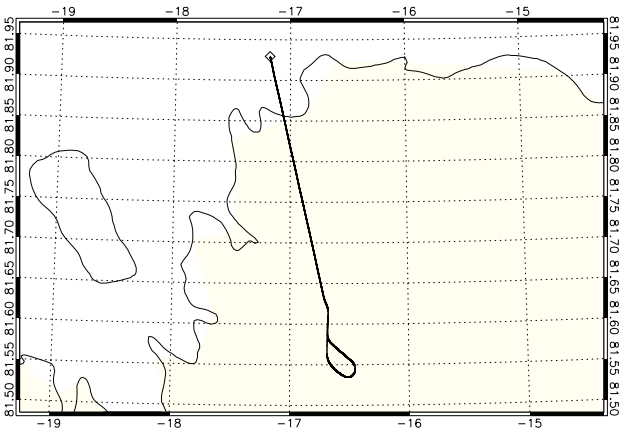


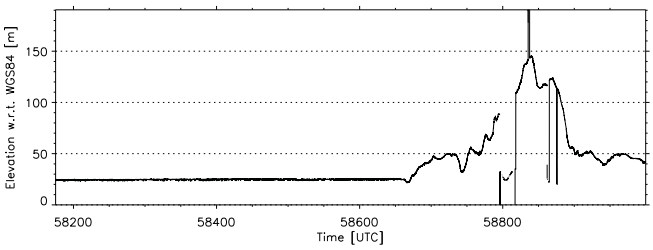


Date	2016-04-08	**Instrument Mode**	Adv. Low Altitude
Start Time	15:22:38 (55358)	**Aircraft**	BAS Twin Otter
Stop Time	16:09:31 (58171)	**Retracker**	OCOG
Distance	198.448 km	**INS Resolution**	50 Hz
Duration	00 h 46 m 54 s	**Processor Version**	0403

A160408_05

AS60A05_ASIWL1B040320160408T160934_20160408T162319_0001.DBL

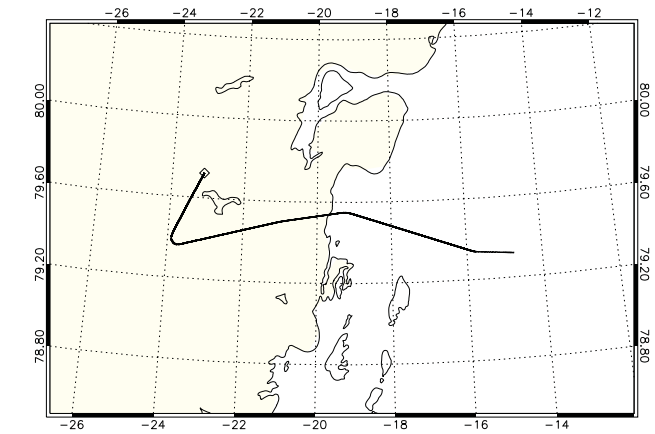


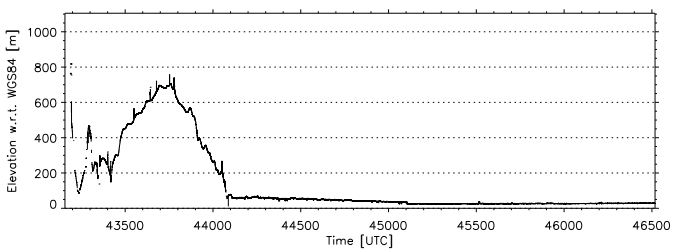


Date	2016-04-08	**Instrument Mode**	Adv. Low Altitude
Start Time	16:09:35 (58175)	**Aircraft**	BAS Twin Otter
Stop Time	16:23:19 (58999)	**Retracker**	OCOG
Distance	57.053 km	**INS Resolution**	50 Hz
Duration	00 h 13 m 45 s	**Processor Version**	0403

A160409_00

AS60A00_ASIWL1B040320160409T115916_20160409T125517_0001.DBL

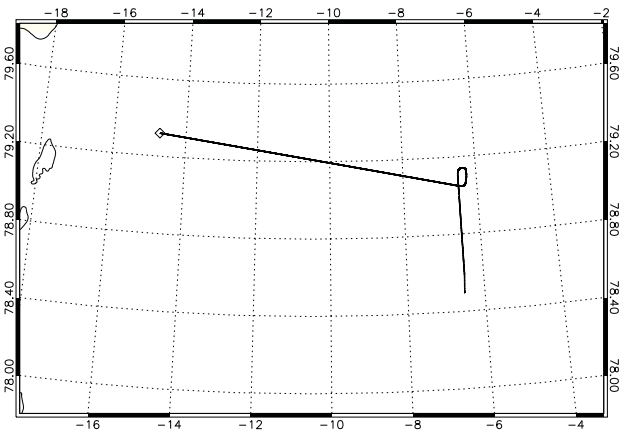


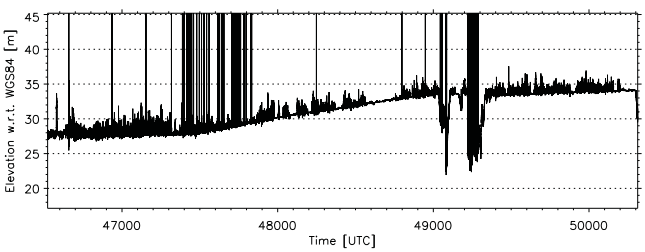


Date	2016-04-09	**Instrument Mode**	Adv. Low Altitude
Start Time	11:59:17 (43157)	**Aircraft**	BAS Twin Otter
Stop Time	12:55:17 (46517)	**Retracker**	OCOG
Distance	234.627 km	**INS Resolution**	50 Hz
Duration	00 h 56 m 01 s	**Processor Version**	0403

A160409_01

AS60A01_ASIWL1B040320160409T125521_20160409T135832_0001.DBL

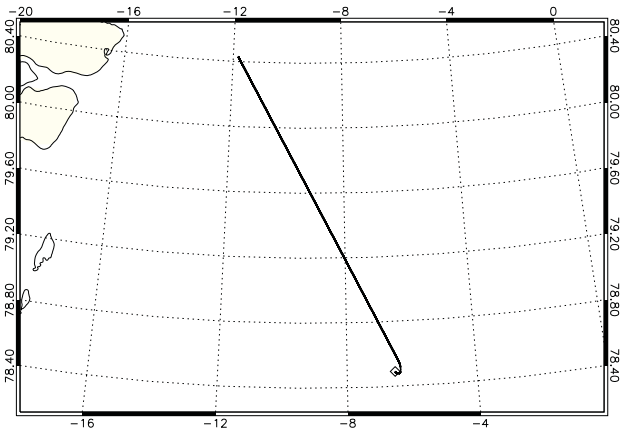


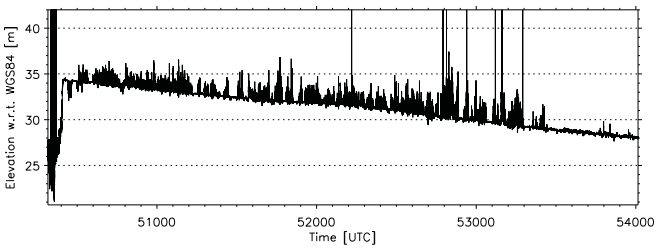


Date	2016-04-09	**Instrument Mode**	Adv. Low Altitude
Start Time	12:55:22 (46522)	**Aircraft**	BAS Twin Otter
Stop Time	13:58:32 (50312)	**Retracker**	OCOG
Distance	262.899 km	**INS Resolution**	50 Hz
Duration	01 h 03 m 11 s	**Processor Version**	0403

A160409_02

AS60A02_ASIWL1B040320160409T135836_20160409T150013_0001.DBL

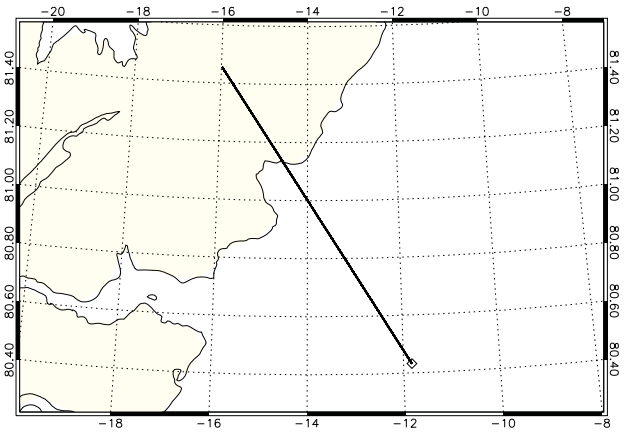


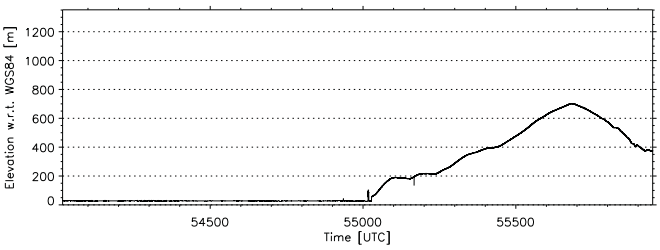


Date	2016-04-09	Instrument Mode	Adv. Low Altitude
Start Time	13:58:37 (50317)	Aircraft	BAS Twin Otter
Stop Time	15:00:13 (54013)	Retracker	OCOG
Distance	247.859 km	INS Resolution	50 Hz
Duration	01 h 01 m 37 s	Processor Version	0403

A160409_03

AS60A03_ASIWL1B040320160409T150016_20160409T153227_0001.DBL

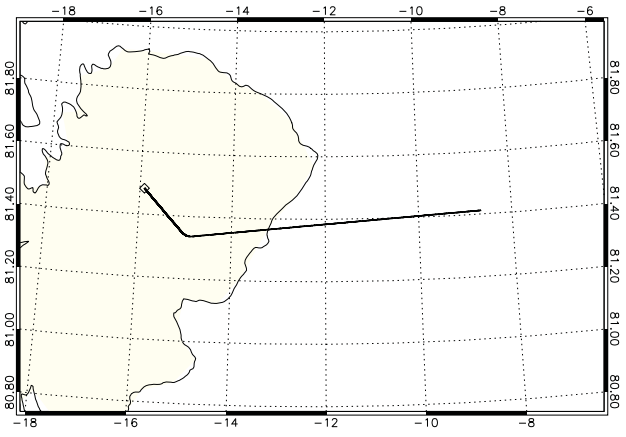


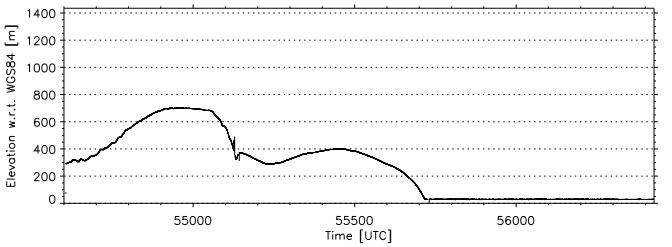


Date	2016-04-09	Instrument Mode	Adv. Low Altitude
Start Time	15:00:17 (54017)	Aircraft	BAS Twin Otter
Stop Time	15:32:27 (55947)	Retracker	OCOG
Distance	134.927 km	INS Resolution	50 Hz
Duration	00 h 32 m 11 s	Processor Version	0403

A160410_00

AS60A00_ASIWL1B040320160410T150959_20160410T160210_0001.DBL

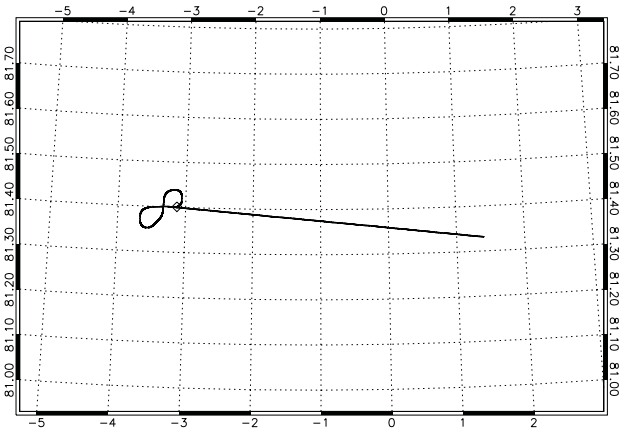


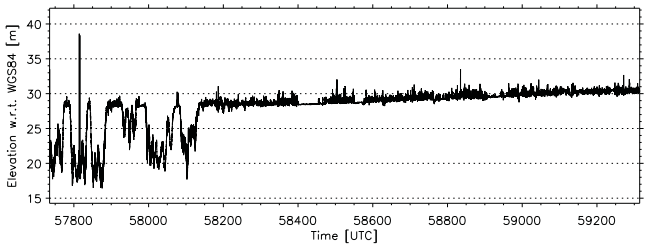


Date	2016-04-10	Instrument Mode	Adv. Low Altitude
Start Time	15:10:00 (54600)	Aircraft	BAS Twin Otter
Stop Time	15:40:26 (56426)	Retracker	OCOG
Distance	128.039 km	INS Resolution	50 Hz
Duration	00 h 30 m 27 s	Processor Version	0403

A160410_01

AS60A01_ASIWL1B040320160410T160214_20160410T170019_0001.DBL





Date	2016-04-10	Instrument Mode	Adv. Low Altitude
Start Time	16:02:15 (57735)	Aircraft	BAS Twin Otter
Stop Time	16:28:34 (59314)	Retracker	OCOG
Distance	108.942 km	INS Resolution	50 Hz
Duration	00 h 26 m 19 s	Processor Version	0403

A160410_02

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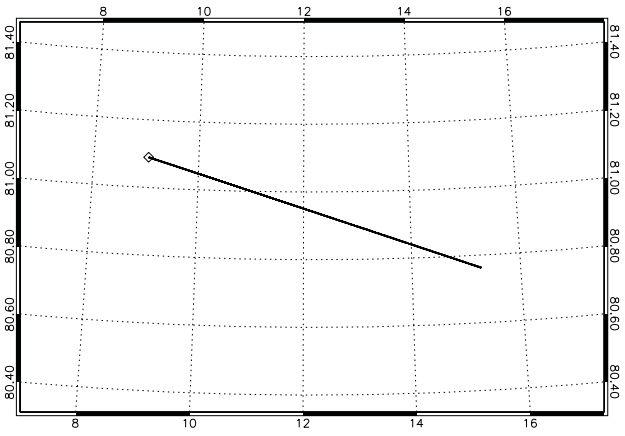
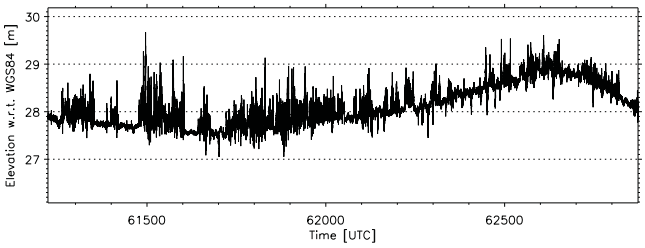
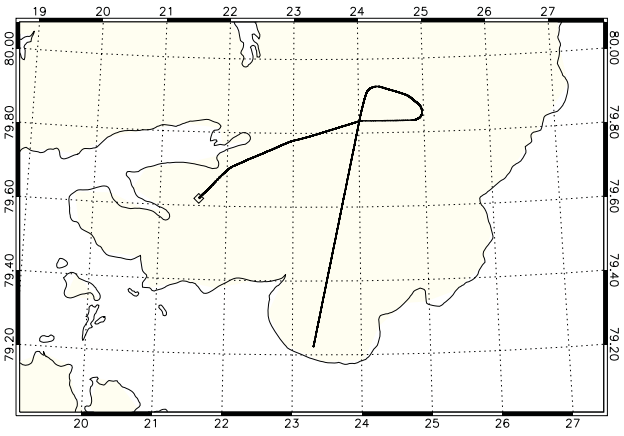


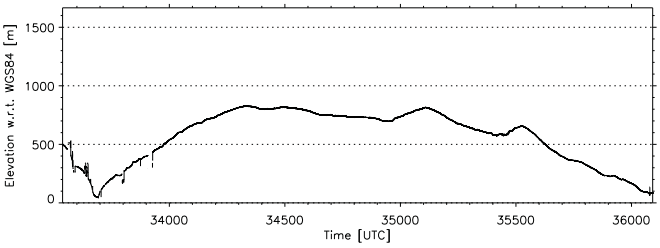


Date	2016-04-10	Instrument Mode	Adv. Low Altitude
Start Time	17:00:23 (61223)	Aircraft	BAS Twin Otter
Stop Time	17:27:53 (62873)	Retracker	OCOG
Distance	115.119 km	INS Resolution	50 Hz
Duration	00 h 27 m 30 s	Processor Version	0403

A160415_00

AS60A00_ASIWL1B0403201604 15T091857_20160415T100131_0001.DBL





Date	2016-04-15	Instrument Mode	Adv. Low Altitude
Start Time	09:18:58 (33538)	Aircraft	BAS Twin Otter
Stop Time	10:01:31 (36091)	Retracker	OCOG
Distance	173.228 km	INS Resolution	50 Hz
Duration	00 h 42 m 34 s	Processor Version	0403

A160415_01

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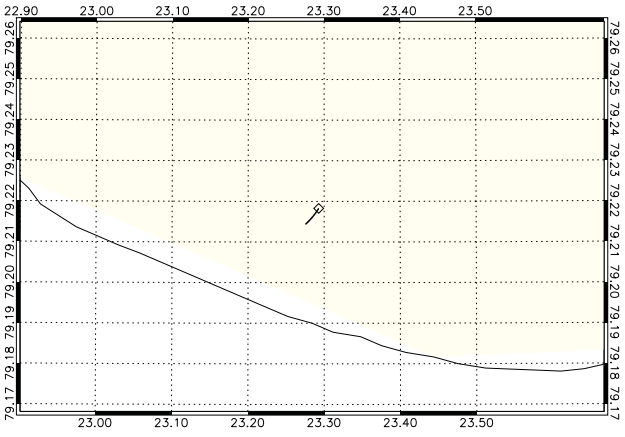
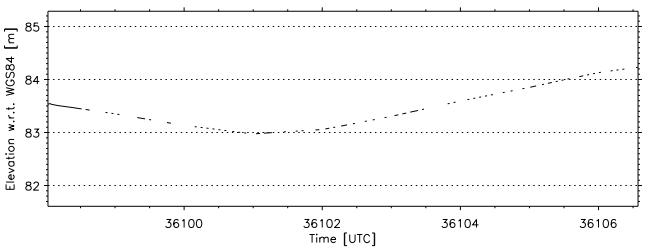
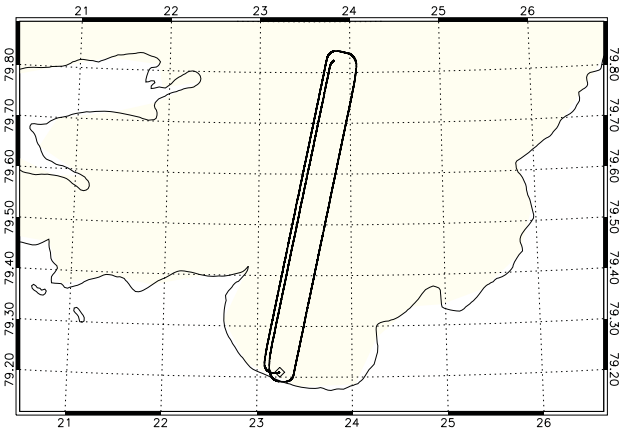


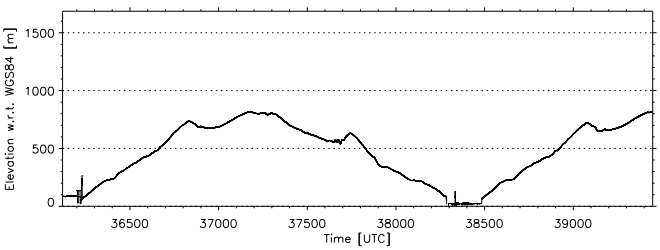


Date	2016-04-15	Instrument Mode	Adv. Low Altitude
Start Time	10:01:38 (36098)	Aircraft	BAS Twin Otter
Stop Time	10:01:46 (36106)	Retracker	OCOG
Distance	0.571 km	INS Resolution	50 Hz
Duration	00 h 00 m 09 s	Processor Version	0403

A160415_02

AS60A02_ASIWL1B0403201604 15T100159_20160415T105727_0001.DBL





Date	2016-04-15	Instrument Mode	Adv. Low Altitude
Start Time	10:02:00 (36120)	Aircraft	BAS Twin Otter
Stop Time	10:57:27 (39447)	Retracker	OCOG
Distance	227.709 km	INS Resolution	50 Hz
Duration	00 h 55 m 28 s	Processor Version	0403

A160415_03

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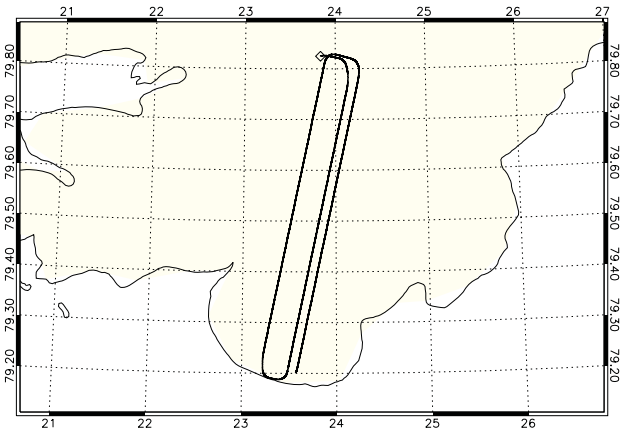
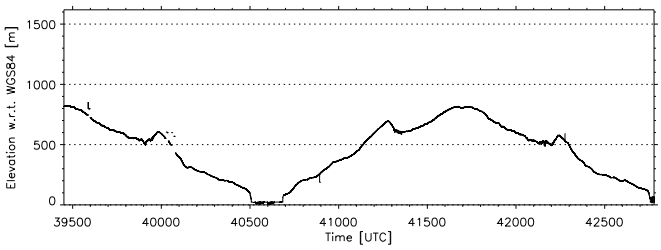
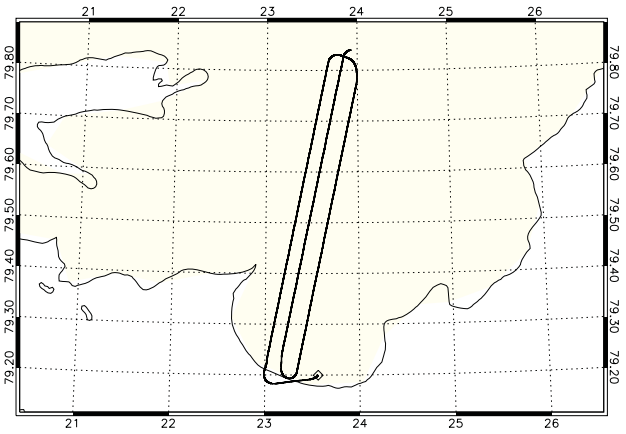


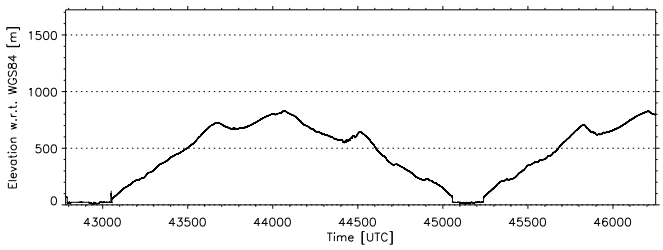


Date	2016-04-15	**Instrument Mode**	Adv. Low Altitude
Start Time	10:57:31 (39451)	**Aircraft**	BAS Twin Otter
Stop Time	11:52:58 (42778)	**Retracker**	OCOG
Distance	228.628 km	**INS Resolution**	50 Hz
Duration	00 h 55 m 27 s	**Processor Version**	0403

A160415_04

AS60A04_ASIWL1B0403201604151115301_20160415T125050_0001.DBL

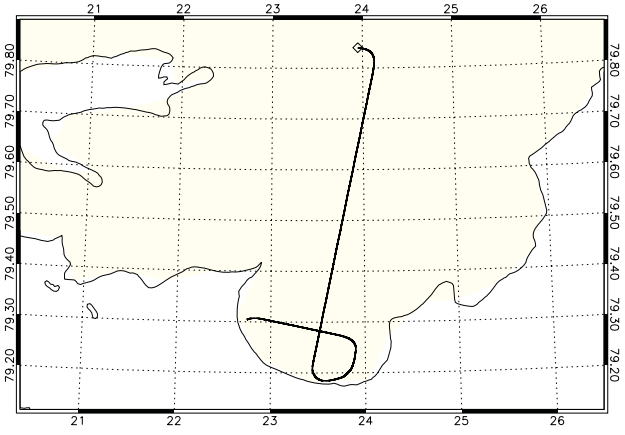


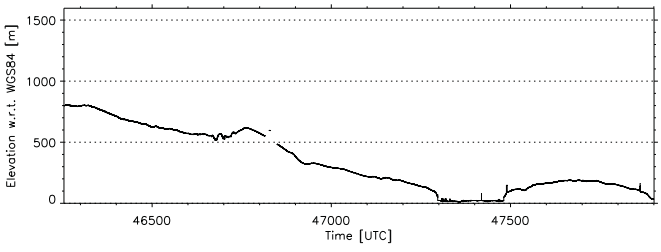


Date	2016-04-15	**Instrument Mode**	Adv. Low Altitude
Start Time	11:53:02 (42782)	**Aircraft**	BAS Twin Otter
Stop Time	12:50:51 (46251)	**Retracker**	OCOG
Distance	236.755 km	**INS Resolution**	50 Hz
Duration	00 h 57 m 49 s	**Processor Version**	0403

A160415_05

AS60A05_ASIWL1B0403201604151125053_20160415T131820_0001.DBL

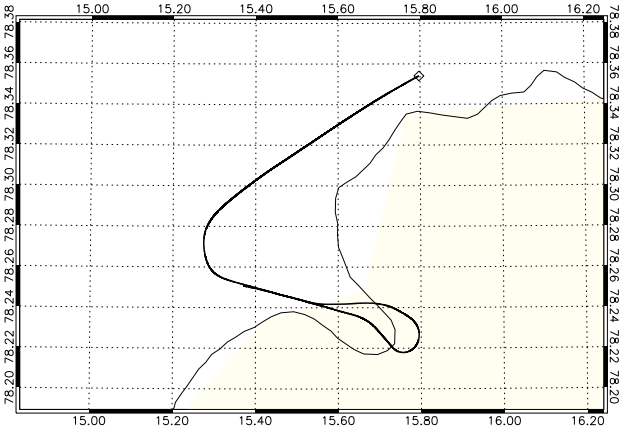


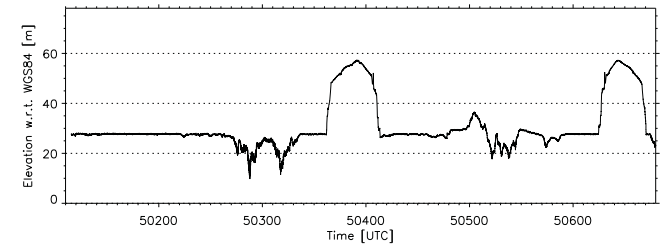


Date	2016-04-15	**Instrument Mode**	Adv. Low Altitude
Start Time	12:50:54 (46254)	**Aircraft**	BAS Twin Otter
Stop Time	13:18:20 (47900)	**Retracker**	OCOG
Distance	115.035 km	**INS Resolution**	50 Hz
Duration	00 h 27 m 26 s	**Processor Version**	0403

A160415_06

AS60A06_ASIWL1B0403201604151135509_20160415T140439_0001.DBL

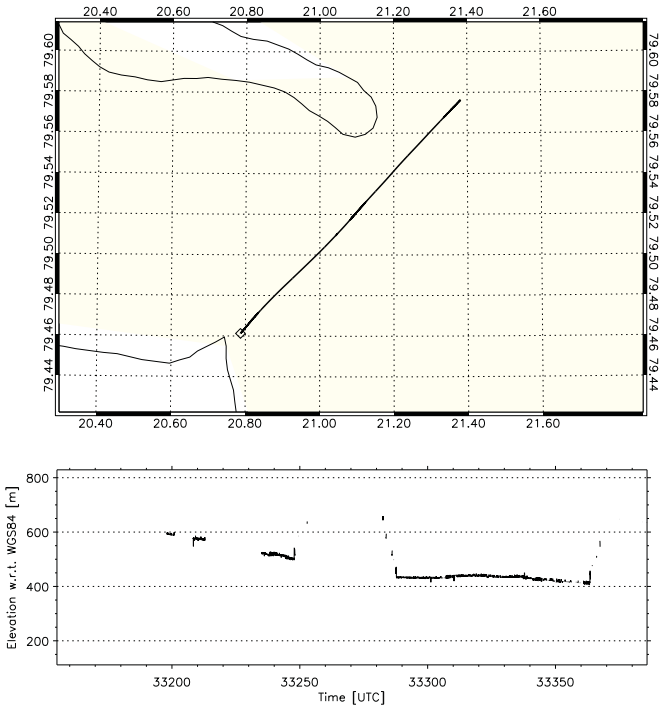




Date	2016-04-15	**Instrument Mode**	Adv. Low Altitude
Start Time	13:55:10 (50110)	**Aircraft**	BAS Twin Otter
Stop Time	14:04:39 (50679)	**Retracker**	OCOG
Distance	40.563 km	**INS Resolution**	50 Hz
Duration	00 h 09 m 30 s	**Processor Version**	0403

A160416_00

AS60A00_ASIWL1B0403201604 16T091234_20160416T091625_0001.DBL



Date	2016-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	09:12:35 (33155)	**Aircraft**	BAS Twin Otter
Stop Time	09:16:25 (33385)	**Retracker**	OCOG
Distance	17.585 km	**INS Resolution**	50 Hz
Duration	00 h 03 m 51 s	**Processor Version**	0403

A160416_01

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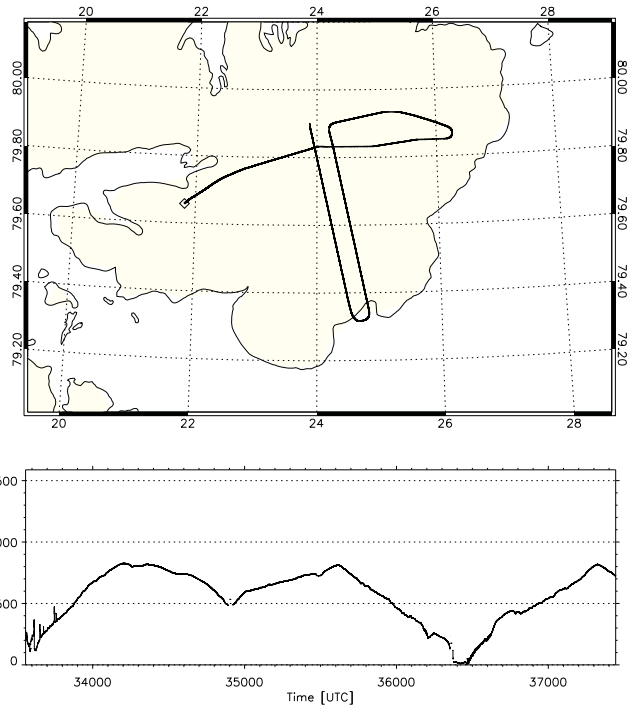
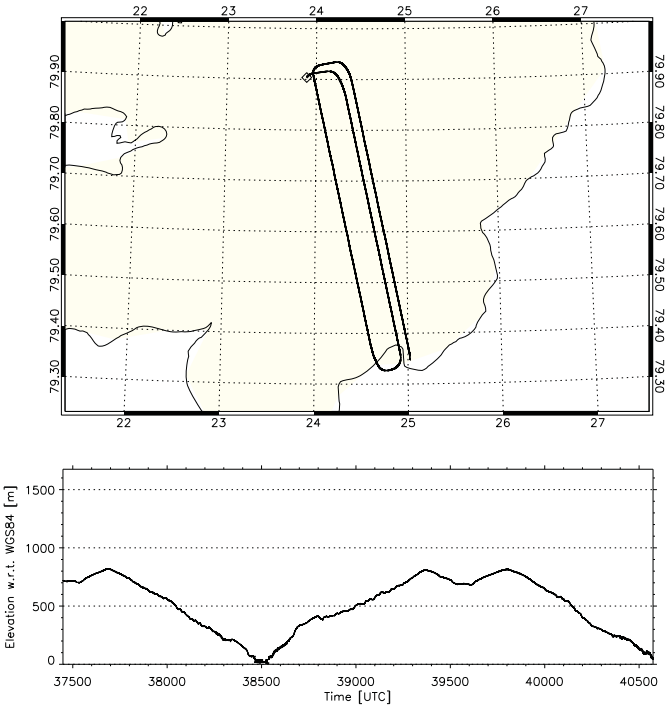


Date	2016-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	09:19:18 (33558)	**Aircraft**	BAS Twin Otter
Stop Time	10:24:03 (37443)	**Retracker**	OCOG
Distance	271.271 km	**INS Resolution**	50 Hz
Duration	01 h 04 m 45 s	**Processor Version**	0403

A160416_02

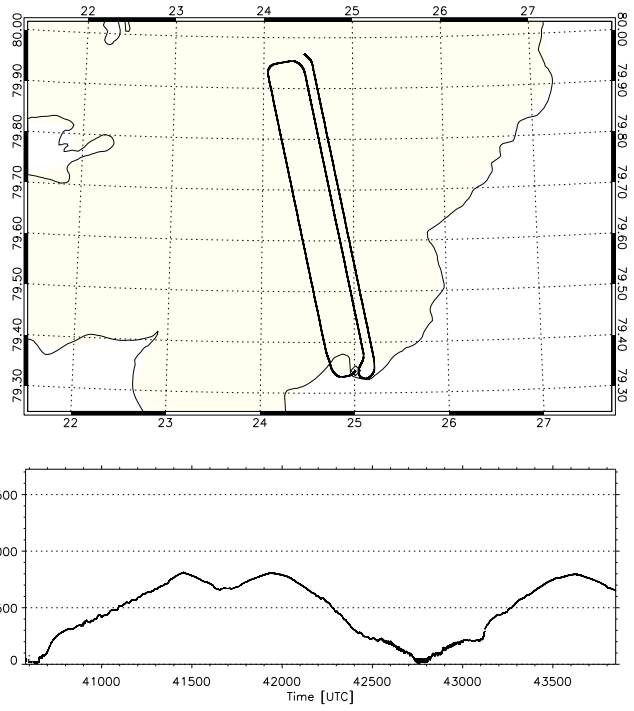
AS60A02_ASIWL1B0403201604 16T102407_20160416T111613_0001.DBL



Date	2016-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	10:24:08 (37448)	**Aircraft**	BAS Twin Otter
Stop Time	11:16:13 (40573)	**Retracker**	OCOG
Distance	217.466 km	**INS Resolution**	50 Hz
Duration	00 h 52 m 06 s	**Processor Version**	0403

A160416_03

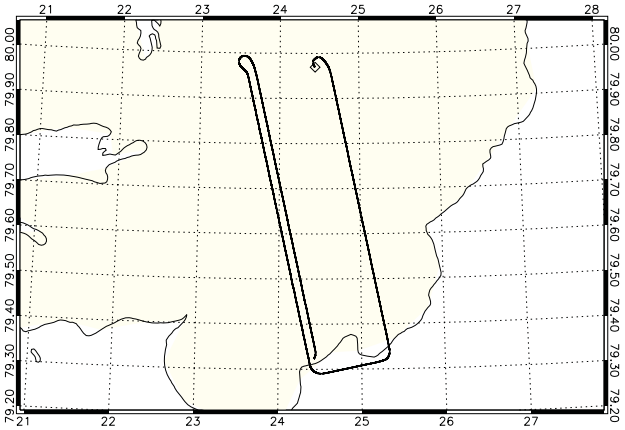
AS60A03_ASIWL1B0403201604 16T111618_20160416T121047_0001.DBL

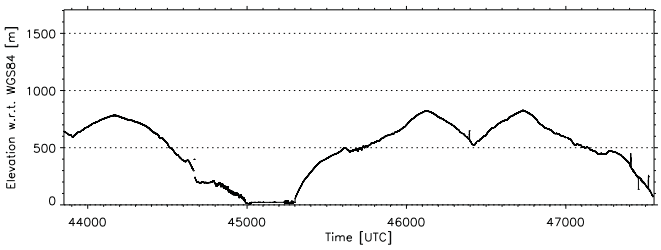


Date	2016-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	11:16:19 (40579)	**Aircraft**	BAS Twin Otter
Stop Time	12:10:47 (43847)	**Retracker**	OCOG
Distance	226.663 km	**INS Resolution**	50 Hz
Duration	00 h 54 m 29 s	**Processor Version**	0403

A160416_04

AS60A04_ASIWL1B0403201604l6T121050_20160416T131233_0001.DBL





Date	2016-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	12:10:51 (43851)	**Aircraft**	BAS Twin Otter
Stop Time	13:12:33 (47553)	**Retracker**	OCOG
Distance	257.565 km	**INS Resolution**	50 Hz
Duration	01 h 01 m 43 s	**Processor Version**	0403

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ISBN-978-87-91694-41-7