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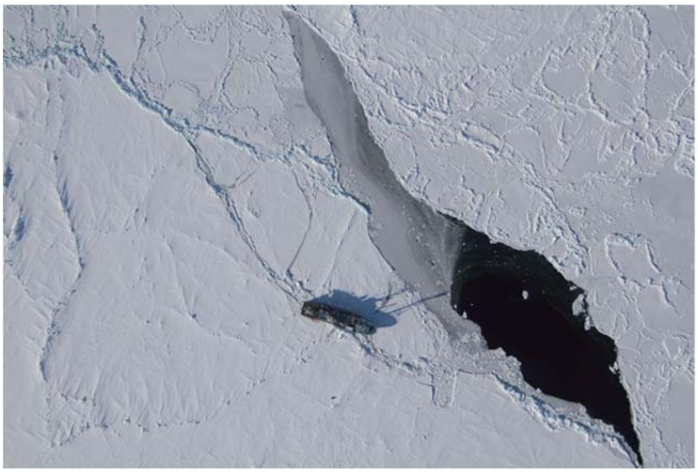

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This volume consists of 2 independent reports:

ICE-ARC airborne campaign 2015

Data collection and processing report

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Pages 33

ESA GNSS FinExp 2015

Additional airborne activity in the Baltic Sea during the SPIR campaign

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Pages 21

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Front page: BAS Twin Otter (VP-FAZ) at Station Nord (upper), and RV Lance frozen into the ice during the N-ICE2015 expedition (lower left), credits S. M. Hvidegaard. The Baltic Sea (lower right), credits H. Skourup

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ICE-ARC airborne campaign 2015

DATA COLLECTION AND PROCESSING REPORT

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ICE-ARC
ICE • CLIMATE • ECONOMICS

Contents

1. Introduction

The British Antarctic Survey (BAS) and the Danish National Space Institute (DTU Space) coordinated an airborne campaign in the period April 13-24, 2015 as part of ICE-ARC project (Ice, Climate, Economics – Arctic Research on Change). The ICE-ARC programme is funded by the EU 7th framework programme running from 2014 to 2017.

Coincident laser/radar measurements over sea ice were collected in the Fram Strait, north of Svalbard and north of Station Nord. The laser measurements give information on sea ice freeboard and ridges/leads distribution, while the CryoSat-type 13 GHz radar altimeter (ASIRAS) gives information on radar penetration into the snow. The measurements north of Greenland and Svalbard are partially a continuation of time series of sea ice changes by various airborne campaigns since 1998.

Two overflights of the validation site near RV Lance were conducted on April 19 and 24, including short parallel lines (mow-the-lawn) near the ship, and longer lines aligned with EM soundings obtained by helicopter. These data, together with NASA's Operation IceBridge overflight of RV Lance on March 19, gives a unique combination of in situ measurements with airborne sensors to obtain information of snow and sea ice properties for validation of CryoSat-2 sea ice thickness and sea surface height.

For the airborne campaign, a BAS Twin Otter (VP-FAZ) was equipped with a laser scanner, the Airborne Synthetic Interferometer Radar System (ASIRAS), and an airborne meteorology system (MASIN) to map the sea ice and ice sheet topography together with atmospheric properties. The operations were coordinated with the Norwegian Young Sea ICE cruise (N-ICE) organized by Norwegian Polar Institute (NPI) where observations of sea ice properties were based out of the research vessel Lance.

This report is part of ICE-ARC deliverable 1.62, and describes the data collection and the data processing carried out by DTU Space for this airborne campaign 2015 with focus on the laser and radar altimetry measurements.

2. Summary of operation

Figure 1 shows an overview of the flight tracks from the ICE-ARC 2015 airborne campaign, shown with blue lines, red circles mark the location of the validation sites observed from RV Lance and green indicated similar airborne survey lines by the Operation Ice Bridge team. In addition a few survey lines were added near Helsinki, Finland after the Arctic surveys. These flights were funded by the European Space Agency to provide ground-truth for the Software PARIS Interferometric Receiver (SPIR) experiment.

The ICE-ARC airborne operations were based out of Longyearbyen, Svalbard and Station Nord, Greenland after the equipment was installed in the aircraft in Cambridge by BAS personnel.

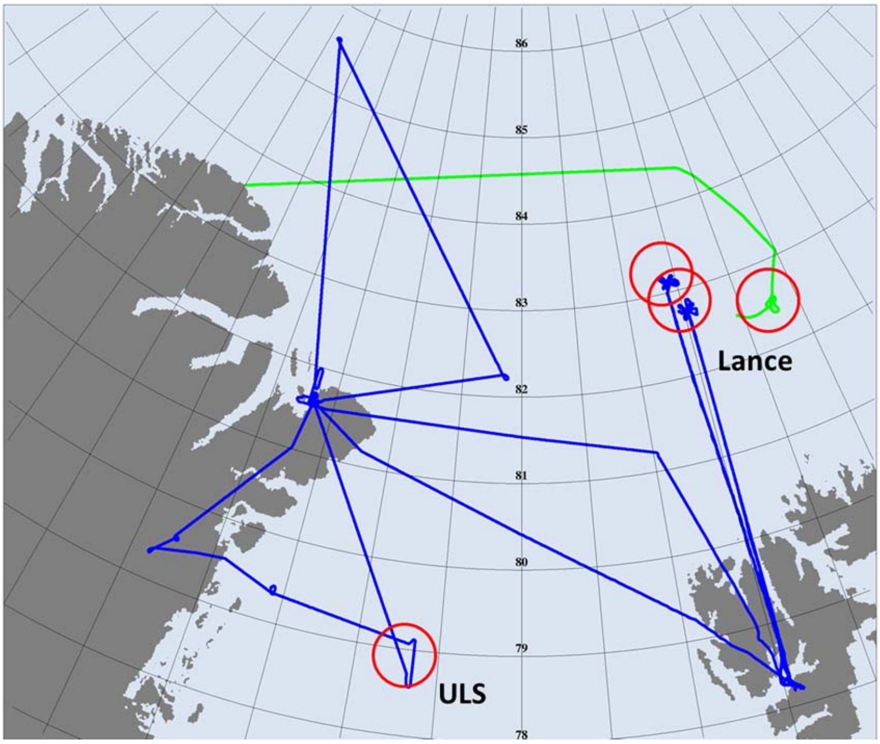


Figure 1: Overview of the flight tracks from the ICE-ARC airborne campaign 2015 (ICE-ARC flights in blue, OIB flight in green) is shown here. The circles outline the location of the validation sites, where scientists were located to take in situ measurements of snow and ice properties.

The main purpose was to overfly the research vessel RV Lance, where scientists from the Norwegian Polar Institute (NPI) measured the sea ice and snow properties *in situ*, as part of the N-ICE expedition. The airborne campaign was a success and a unique data set for analysis with the in situ data and validation of CryoSat-2 has been collected, including:

- Two overflights of the validation site near RV Lance on April 19 and 24, including short parallel lines (mow-the-lawn) near the ship for both flights, together with two longer lines aligned with EM soundings obtained by helicopter for the second flight
- Overflight of sea ice in the Fram Strait including a moorings upward looking sonars run by NPI, April 21
- Overflight of survey site on fast ice near Station Nord, and repeat flight lines from previous years out of Station Nord, April 20

A more detailed overview of flights is provided in Table 1.

Table 1 : Overview of flights, dates, and personnel

Date	DOY	Flight	Survey operators*	Comment
16-04-2015	106		RL/SMH	Testflight
19-04-2015	109	A	RL/SMH	LYR-Lance-LYR
19-04-2015	109	B	RL/SMH	LYR-EN-NRD
20-04-2015	110		RL/SMH	NRD-F-C-NRD
21-04-2015	111		RL/SMH	NRD-79F-ULS-NRD
22-04-2015	112		RL/SMH	NRD-P2-LYR
24-04-2015	114		RL/SMH	LYR-Lance2-LYR
03-05-2015	123		RL/HSK	SPIR lines from MALMI airport

*Survey operators: Russ Ladkin (RL) BAS, Sine Munk Hvidegaard (SMH) and Henriette Skourup (HSK) both from DTU Space

3. Hardware Installation

The hardware installation in the BAS aircraft (reg. VP-FAZ) consisted of the following instruments:

- ESA ku-band interferometric radar ASIRAS
- BAS Airborne Laser Scanner (ALS) of the type Riegl LMS Q-240i-80
- One NovAtel GPS kindly loaned by AWI to support ASIRAS operation
- Two geodetic dual-frequency GPS receivers (Trimble 5700, Javad delta) together with a Javad AT4; a 4 antenna array for backup attitude and velocity determination. The Trimble and AT4 receivers were connected to the aft antenna, whereas the stand alone Javad delta was connected to the front antenna.
- An Inertial navigation system (INS) of the type Honeywell H-764G (Primary INS)
- An INS of the type OxTS Inertial+2 (Backup INS)
- Meteorological Airborne Survey Instrumentation (MASIN)
- DSLR Camera (Canon EOS 7D)

The instruments were mounted in the aircraft and tested in Cambridge before the departure for the ICE-ARC campaign. The lever arms from GPS antenna to ASIRAS and ALS reference points are given in Table 2, and the hardware installation can be seen in Figure 2 and 3.

Table 2: Overview of the dx, dy, and dz offsets for the lever arm from the GPS antenna to the origin of the laser scanner and the back centre of the ASIRAS antenna.

To laser scanner	**dx (m)**	**dy (m)**	**Dz (m)**
from GPS front antenna	- 4.76	- 0.31	+ 1.58
to ASIRAS antenna	**dx (m)**	**dy (m)**	**dz (m)**
From GPS front antenna	-5.85	-0.31	+1.95

Figure 2: Instrument installation in the camera bay below the floor in the Twin Otter. ALS (left), OxTS INS (middle right) and Trimble GPS receiver (lower right). Note ALS and OxTS INS axis are mounted along the aircraft center line.

Figure 3 Picture taken from the back of the Twin Otter. ASIRAS instrument is in the aft rack and control computers in the other racks. The Honeywell INS was mounted on the floor under the seat.

4. GPS and INS data processing

The two GPS receivers on board the aircraft collected time and position data continuously during the flights. These GPS receivers, named AIR1 (Javad Delta) and TRIM (Trimble 5700), were both connected to the aft antenna.

The position of the aircraft is found from kinematic solutions of the GPS data collected during flight using Waypoint software GrafNav versions 8.30 and 8.40. Two methods can be used for post-processing of GPS data, kinematic differential processing and precise point positioning. 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.

During the calibration flights in Longyearbyen a reference station was placed in the airport. . The exact position of the base station was found using the online service AUSPOS (http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos).

Kinematic GPS processing

Table 33 shows an overview of the GPS data collected, together with information on which one of these is the preferred solution, which will be used in the further processing. The Trimble data had reduced quality for unknown reasons and therefore the AIR1 has been used throughout the data processing. For most files the precise point positioning (PPP) gave the best solutions with lowest vertical standard deviation and fewest gaps. In general, the solutions from the campaign are of poorer quality compared to similar campaigns perhaps due to larger ionospheric activity.

Table 3 : GPS data overview

DOY	AIR1	TRIM*	Javad	Reference station	Preferred solution	Filename
106	X	X	X	LYR	AIR1	106_air1_ppp.p
107	X	X	X	LYR2	AIR1	Multiple
109a	X	X	X	LYR, NYA1	AIR1	109a_air1_ppp.p
109b	X	X	X		AIR1	109b_air1_ppp.p
110	X	X	X	STN	AIR1	110_air1_ppp.p
111	X	X	X	STN	AIR1	111_air1_ppp.p
112	X	X	X	Multi	AIR1	112_air1_ppp.p
114	-	X	-	LYR, NYA1	AIR1	114_air1_ppp.p

*TRIM poor solution for all files

Static GPS processing of calibration building in Longyearbyen

A large building in Longyearbyen was surveyed on April 17 (DOY 107) with the purpose to act as a calibration building for ALS measurements. These data have been processed with a combination of AUSPOS and Waypoint GrafNet option for static processing. The building is located at position (N 78 13.45, E 15 39.15) near the water front on a flat spot, such that crossings of the building are possible through the valley and along the coastline. A plot of the location, as well as GPS measurement and ALS elevations of the building can be seen in Figure 4. The exact positions of the GPS measurement points 0001-0008 is given in Table 4.

Figure 4 Calibration building in Longyearbyen. Location (upper plot), measurement of the building (lower left) and ALS DEM of the building together with markings of the measurement points (lower right).

Table 4 : Positions of the GPS measurement points 0001-0008 of calibration building in Longyearbyen

GPS marking	Latitude (dec. deg)	Longitude (dec. deg)
0001	78.2239290587	15.6533106878
0002	78.2240225870	15.6536291657
0003	78.2240941058	15.6510663820
0004	78.2242257750	15.6499457030
0005	78.2242781068	15.6537551007
0006	78.2242331242	15.6539555882
0007	78.2244150013	15.6515191797
0008	78.2243908372	15.6511486099

GPS/INS solutions

The position from the GPS solution is combined with attitude information (pitch, roll and heading) from the inertial navigation system. Here is only used data from the primary INS Honeywell (H-764G), as the attitude of the backup instrument (OxTS) is found to have degraded accuracy during acceleration, which includes turns and rapid changes of altitude (Skourup et al, 2012). The raw data recovered from the Honeywell was sampled at 10 Hz and merged with the GPS solution 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.

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

In this way a smooth GPS-INS solution is obtained, which can be used for geolocation of radar and laser altimetry observations.

The selected INS solutions are listed in Table 5. As seen in the Table, only one flight on DOY 112 uses data from the backup unit (OxTS). Here the PC supporting the H-764G EGI had to be rebooted during flight causing loss of data early in the survey.

Table 5 : Overview of combined GPS and INS solutions used in the further processing

DOY	GPS Solution	Comments*	EGI/OXTS	GPS Start/stop	INS start/stop
106	106_air1_ppp.p	8a/17 0 f 1	H-764G	085731-100321	090000-100001
109a	109a_air1_ppp.p		H-764G	092647-150902	092722-150813
109b	109b_air1_ppp.p		H-764G	161648-194845	163112-194801
110	110_air1_ppp.p		H-764G	111938-171826	113936-171501
111	111_air1_ppp.p		H-764G	095850-153553	100000-153449
112	112_air1_ppp.p	EGI pc down 10:48, fitted 10.696-10.701	OXTS (H-764G)	101411-134922	103712-134837
114	114_air1_ppp.p		H-764G	091153-144502	091312-144349

5. Airborne laser scanner (ALS) data

The laser scanner operates with wavelength 904 nm. The pulse repetition frequency is 10,000 Hz and the ALS scans 40 lines per second, using a data rate of 250 pulses per line. This corresponds to a horizontal resolution of 1 m x 1 m at a flight height of 300 m and a ground speed of 250 kph. The across-track swath width is roughly 2/3 of the flight height, and the vertical accuracy is less than 10 cm depending primarily on uncertainties in the kinematic GPS-solutions. An example of processed ALS elevations is given in Figure 5. The raw logged files with start/stop times are listed in Table 6.

In order to calibrate the ALS data to obtain best possible accuracy, the pitch, roll and heading is constrained by analysing crossing ALS tracks, and minimizing the height difference in the crossing points. Additionally the calibration is tuned to ground control points from a building in Longyearbyen surveyed by GPS on April 17th (see Figure 4) together with a previously surveyed building at St. Nord.

One set of calibration angles is identified for each day, and the results of these calibrations are listed in Table 66. The calibration is found to be constant for the entire campaign as would be expected from the installation where the laser scanner is mounted in the protected camera bay below the floor.

The processing of ALS data is done by combining GPS/INS navigation information with laser range measurements using the geometry of the installation and information from the calibration. More details can e.g. be found in (Hvidegaard et al. 2015 – technical report of CryoVEx 2014), the same procedures for processing and filtering have been followed. Specific for this campaign is:

- Detailed laser range calibration is determined from data over a smooth fast ice area from April 21. This gives the coefficient of a correction polynomial to be used throughout the campaign
- The synchronization between ALS and GPS/INS is checked for each file. The offset of 16 seconds comes from the GPS –UTC time difference though for a few files the timing is one second early (dt in Table 5)
- Runway overflights are used to verify the calibration angels and inter-calibrate ALS and ASIRAS as described in section 6.

The uncertainty in the ALS point cloud data consists of the sum of inaccuracies in the GPS positioning (main error source), attitude determination from combined GPS and INS, range observation together with the calibration. The statistics from survey crossings can be used as a guideline to the accuracy of the observations. From Table 7 the accuracy is seen to be at the 10 cm level.

Table 6: ALS calibration angles and start/stop times

Date	DOY	Raw ALS files	Start time (dechr)	Stop time (dechr)	angles (pitch/roll/heading)	dt (s)
16-04-2015	106	106_090240.2dd	9.242418	9.980101	0.35 -0.60 -0.40	-15
19-04-2015	109A	109_093132.2dd 109_095720.2dd 109_103233.2dd 109_145215.2dd	11.8727878 10.215225 10.669401 14.879265	12.12327 10.25815* 14.211652 15.102930	0.35 -0.60 -0.40	-15 -16 -16 -16
19-04-2015	109B	109_180059.2dd 109_182435.2dd	18.157943 18.405261	18.265735 19.749054	0.35 -0.60 -0.40	-16 -15
20-04-2015	110	110_144112.2dd 110_154121.2dd 110_155613.2dd 110_161220.2dd 110_164950.2dd 110_170754.2dd 110_175332.2dd	14.682487 15.684992 15.932610 16.201246 16.826383 17.127418 *	15.588570 15.810612 15.960483 16.297097 16.837889 17.142724 *	0.35 -0.60 -0.40	-16 -16 -16 -16 -16 -16 -16
21-04-2015	111	111_100450.2dd 111_122200.2dd 111_123358.2dd 111_141501.2dd	10.476790 12.362241 12.561930 14.245942	12.350820 12.546079 14.236580 15.536822	0.35 -0.60 -0.40	-15 -16 -16 -16
22-04-2015	112	112_102010.2dd 112_102010.2dd 112_125650.2dd 112_130110.2dd 112_130726.2dd 112_132256.2dd 112_132614.2dd 112_134129.2dd	10.648093 11.119522 * * * * 13.441081 13.687075	10.808970 12.877805 * * * * 13.49275* 13.78372*	0.35 -0.60 -0.40 0.0 -0.10 0.80’	-15 -15 * * * * -16 -16
24-04-2015	114	114_091755.2dd 114_093411.2dd 114_095525.2dd 114_133404.2dd 114_140254.2dd	9.492614 9.565466 9.919433 13.563979 14.044180	9.526289 9.79899* 13.543599 13.57041* 14.14255*	0.35 -0.60 -0.40	-15 * -16 * *

* Few data points

Table 7: ALS cross-over statistics

Date	DOY	Validation site	Mean (m)	Std. Dev (m)	Min (m)	Max (m)
16-04-2015	106	LYR building*	0.02	0.78	-33.60	38.28
21-04-2015	111	Flade Isblink	0.06	0.07	-0.34	0.56
21-04-2015	111	RWY, STN**	-0.02	0.12	-4.50	4.03

* Some shadow effects from the building gives the large min/max

** Some snow was removed from the runway in between giving the min/max and affecting the std. dev.

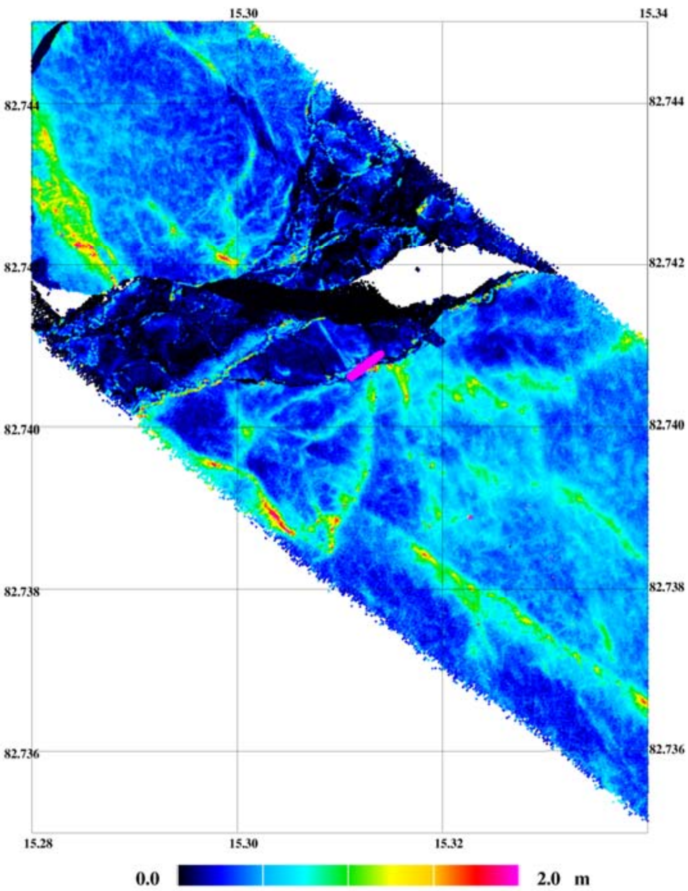


Figure 5: Example of full resolution scan corresponding to the photo of Lance (in pink on the figure) on the cover page.

ALS data format

The processed LiDAR data comes as geo-located point clouds, in lines of width 200-300m at full resolution 1mx1m. For each measurement, information of time, latitude, longitude, heights given with respect to WGS-84 reference ellipsoid, amplitude and scan number (1-251) in a given scanline.

The name convention is given as:

ALS_ SSSSSSSSSSSSSSS-PPPPPP.sbi

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

The ALS files are provided in an 18-bit little-endian binary format. The bit-string is read according to the syntax given in Table 8. In python the data can be read by using the script provided in the text-box below and the final files uploaded to the ICE-ARC repository can be found in Table 9.

Table 8: ALS binary data format

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
Elevation [m]	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
```

Table 9: Overview of processed ALS files

Date	DOY	Final file:	File size (MB)
16-04-2015	106	ALS_20150416T090227_095912.sbi	192
19-04-2015	109A	ALS_20150419T104037_141312.sbi	1486
19-04-2015	109B	ALS_20150419T180925_181557.sbi	34
		ALS_20150419T182419_194508.sbi	771
20-04-2015	110	ALS_20150420T144107_150000.sbi	193
		ALS_20150420T154106_154838.sbi	78
		ALS_20150420T161204_161750.sbi	58
		ALS_20150420T164935_165016.sbi	7
		ALS_20150420T170739_170834.sbi	9
21-04-2015	111	ALS_20150421T102830_122103.sbi	782
		ALS_20150421T122144_123246.sbi	113
		ALS_20150421T123343_141412.sbi	975
		ALS_20150421T141445_154523.sbi	687
22-04-2015	112	ALS_20150422T103849_125216.sbi	1235
24-04-2015	114	ALS_20150424T103118_130353.sbi	1479

6. Radar altimeter (ASIRAS) data processing

The ASIRAS radar operates at 13.5 GHz with footprint size 3 m along-track and 10 m across-track in Low Altitude mode with low resolution (LAM-A) at a standard flight height of 300 m. 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 in the ESA binary format see Cullen (2010). The product includes full waveforms information (see example in Figure 6), and an estimate of the re-tracked height w.r.t. WGS-84 reference ellipsoid using a simple Offset Center of Gravity (OCOG) re-tracker. The re-tracker is not optimal for sea ice applications, but gives a quick estimate of heights. 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 re-tracker 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:

- April 16 (DOY 106) Longyearbyen
- April 20 (DOY 110) Station Nord
- April 24 (DOY 114) Longyearbyen

The data from the runway overflights are available in the applied data set. By using the OCOG re-tracker the offset (ALS-ASIRAS) is -3.46 m with standard deviation 0.06 m.

Also information about roll angles are given as it is common to remove roll angles above/below a certain threshold (±1.5°) due to waveform blurring.

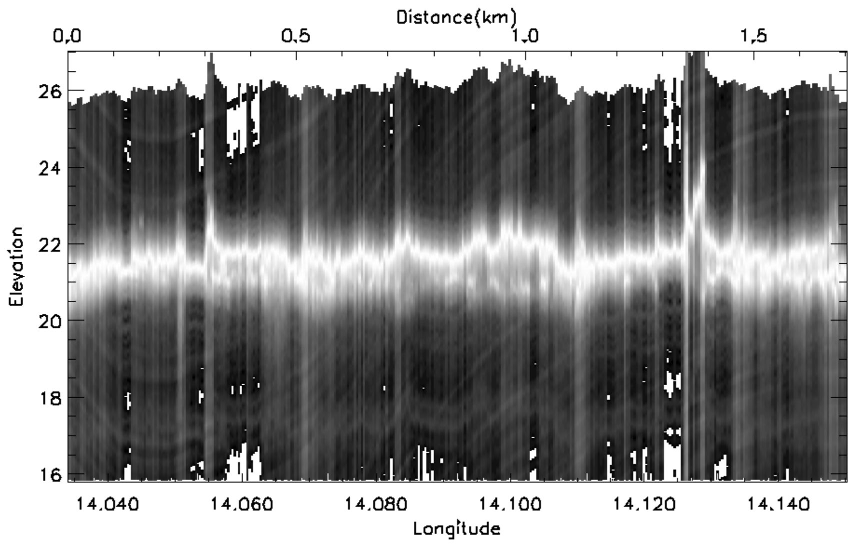


Figure 6: Example of ASIRAS echogram over sea ice, showing two reflecting surfaces

An overview of the processed ASIRAS data is given in Table 9, and plots of each profile are given in Appendix 2.

The file name convention is:

AS30AXX_ASIWL1BNNNN_SSSSSSSSSSSSSSS_PPPPPPPPPPPPPPP_0001.DBL

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

Table 10: Overview of processed ASIRAS files

Date	DOY	Final file:	File size (MB)
16-04-2015		AS6OA00_ASIWL1B040320150416T092449_20150416T093249_0001.DBL	12
		AS6OA01_ASIWL1B040320150416T093254_20150416T094031_0001.DBL	11
19-04-2015		AS6OA00_ASIWL1B040320150419T104233_20150419T114720_0001.DBL	103
		AS6OA01_ASIWL1B040320150419T114724_20150419T130538_0001.DBL	142
		AS6OA02_ASIWL1B040320150419T131609_20150419T140742_0001.DBL	121
		AS6OA04_ASIWL1B040320150419T174737_20150419T175315_0001.DBL	9
		AS6OA05_ASIWL1B040320150419T181154_20150419T191527_0001.DBL	109
		AS6OA06_ASIWL1B040320150419T191531_20150419T193819_0001.DBL	32
20-04-2015		AS6OA00_ASIWL1B040320150420T115822_20150420T123840_0001.DBL	96
		AS6OA01_ASIWL1B040320150420T124308_20150420T134642_0001.DBL	85
		AS6OA02_ASIWL1B040320150420T134646_20150420T145840_0001.DBL	92
		AS6OA03_ASIWL1B040320150420T150351_20150420T160417_0001.DBL	126
		AS6OA04_ASIWL1B040320150420T160423_20150420T164018_0001.DBL	61
		AS6OA05_ASIWL1B040320150420T164812_20150420T170027_0001.DBL	21
21-04-2015		AS6OA00_ASIWL1B040320150421T103707_20150421T110102_0001.DBL	37
		AS6OA01_ASIWL1B040320150421T114603_20150421T121804_0001.DBL	54
		AS6OA02_ASIWL1B040320150421T121807_20150421T132947_0001.DBL	109
		AS6OA03_ASIWL1B040320150421T132951_20150421T134656_0001.DBL	33
		AS6OA04_ASIWL1B040320150421T134802_20150421T145305_0001.DBL	119
		AS6OA05_ASIWL1B040320150421T145308_20150421T152400_0001.DBL	44

Date	DOY	Final file:	File size (MB)
22-04-2015		AS6OA00_ASIWL1B040320150422T104805_20150422T110903_0001.DBL	46
		AS6OA01_ASIWL1B040320150422T110906_20150422T120019_0001.DBL	100
		AS6OA02_ASIWL1B040320150422T120022_20150422T125209_0001.DBL	101
24-04-2015		AS6OA00_ASIWL1B040320150424T103110_20150424T111706_0001.DBL	63
		AS6OA01_ASIWL1B040320150424T111711_20150424T124248_0001.DBL	131
		AS6OA02_ASIWL1B040320150424T124253_20150424T124405_0001.DBL	1
		AS6OA03_ASIWL1B040320150424T124730_20150424T133216_0001.DBL	92
		AS6OA04_ASIWL1B040320150424T143151_20150424T143615_0001.DBL	6

7. Conclusions

The airborne ICE-ARC campaign successfully gathered laser and radar altimetry data over Arctic sea ice in April 2015. The data include two dense surveys near the research vessel Lance coordinated with the N-Ice 2015 cruise, repeated flight lines near NE-Greenland and survey over upward looking sonar buoy in Fram Strait. Unfortunately the repeat triangle flight north of Station Nord is limited due to some issues with the ALS logging system. Internal calibrations of the data show high quality despite reduced accuracy of the GPS solutions.

A unique dataset of coincident altimetry along with in situ data are available for co-analysis and comparison to satellite products. The campaign data products can be downloaded through the ICE-ARC project data archive.

8. References

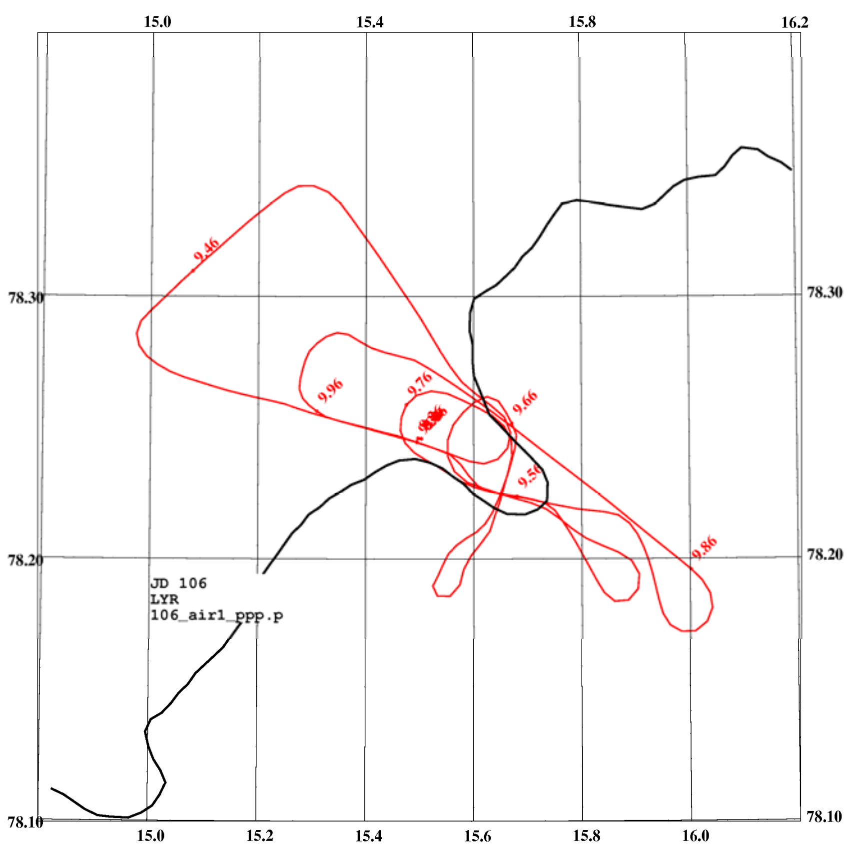
Cullen, R.: CryoVEx Airborne Data Products Description, Issue 2.6.1, ESA, Ref. CS-LI-ESA-GS-0371, 2010

Helm, V. , Hendricks, S. , Göbell, S. , Rack, W. , Haas, C. , Nixdorf, U. and Boebel, T.: CryoVEx 2004 and 2005 (BoB) data acquisition and final report , Alfred Wegener Institute, Bremerhaven, Germany, ESA contract C18677/04/NL/GS, 2006

Hvidegaard, Sine Munk ; Nielsen, Jens Emil ; Sørensen, Louise Sandberg ; Simonsen, Sebastian Bjerregaard ; Skourup, Henriette ; Forsberg, René ; Helm, V. ; Bjerg, T., ESA CryoVEx 2014 - Airborne ASIRAS radar and laser scanner measurements during 2014 CryoVEx campaign in the Arctic, (ISBN: 978-87-91694-26-4)

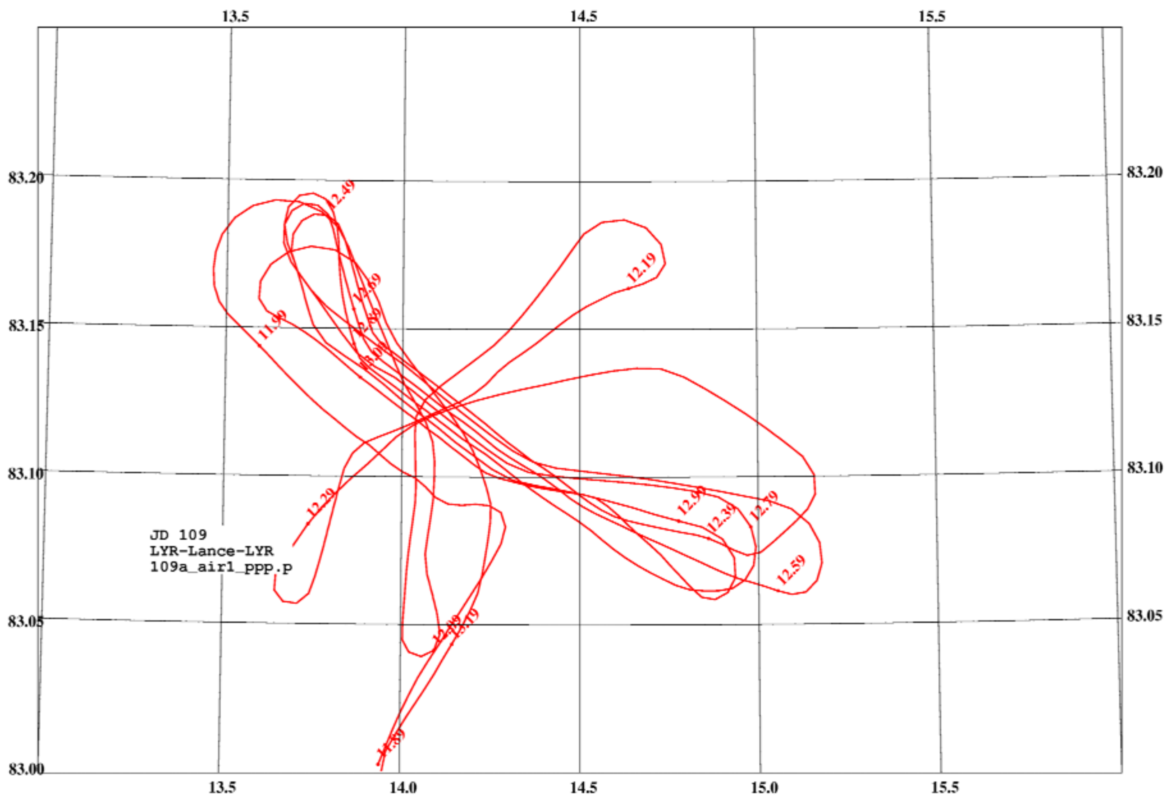
9. Appendix – flight tracks and log

The ground tracks for the chosen preferred GPS solutions are shown in the following figures. Airport codes LYR (Longyearbyen, Svalbard) and STN (Station Nord, Greenland) are used. The GPS tracks are labelled with time in decimal hours. Log notes are listed with the corresponding tracks.



JD 106 16/4-2015 LYR – test

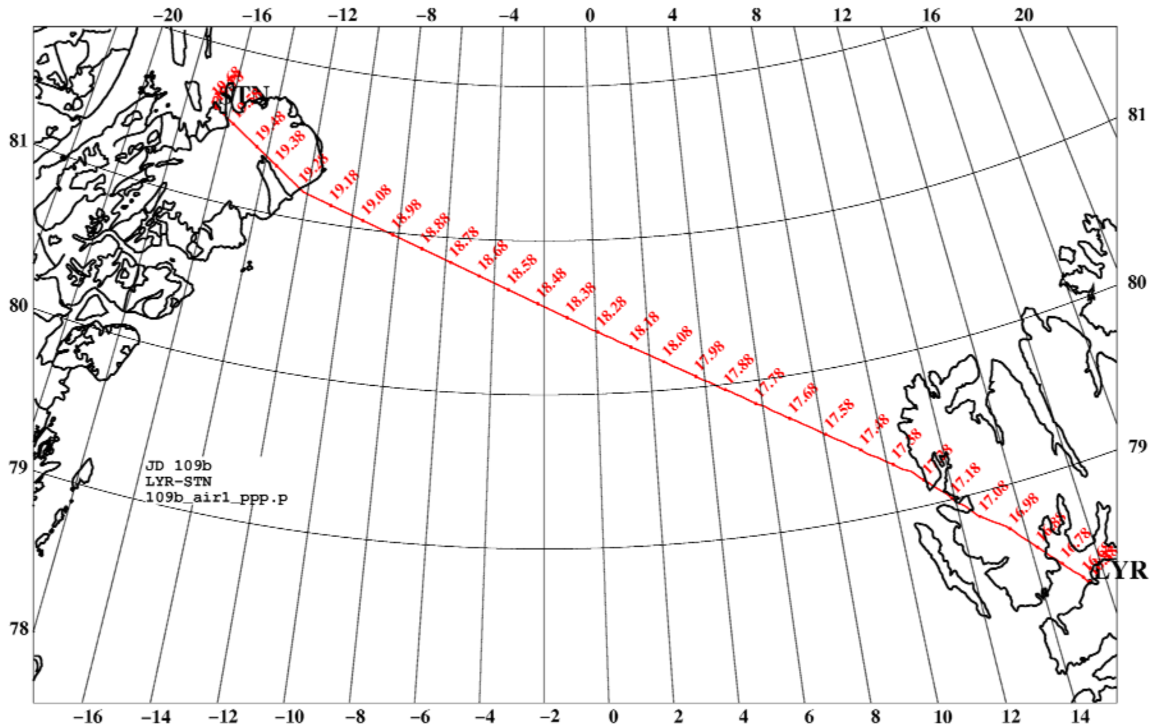
0858	System start up
	EGI start
0914	Taxi
0921	Take off LYR
092450	ASIRAS start log
0928	Turn for rwy
0932	Towards bldg.
0933	Bldg 1st
0937	Bldg 2nd
094020	Bldg 3rd
094320	Bldg 4th
0947	Bldg 1st repeated
095830	Landing

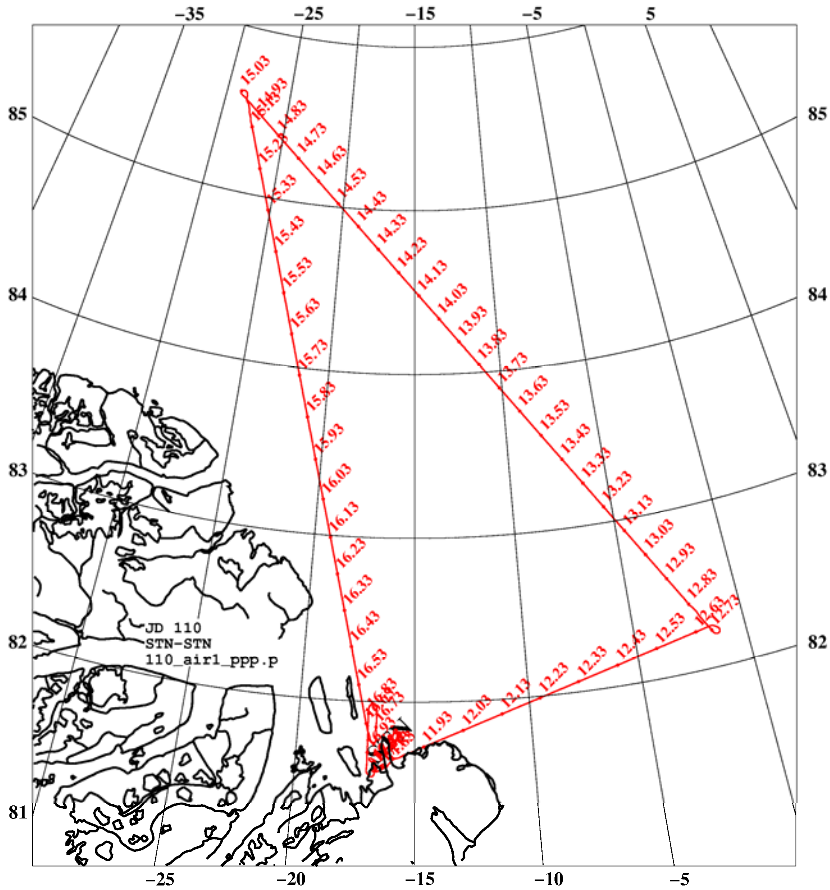


<u>JD 109 18/4-2015 LYR – Lance –LYR-STN</u>	
08-915	De-icing the plane
0930	System start up
	EGI start
0939	Taxi
0942	Take off LYR
0958	ASIRAS on
1001	Calibration
1040	Decending below scattered clouds
104230	Start record _00 over open water
1050	First thin sea ice
1054	Very small broken floes, dense conc.
114725	Stop/start record _01
	Line up for grid
115620	101, Event 1, line repeatedly
	Re-calculate grid, strong winds
121314	Line, Event 2
121341	End line
121819	Start line 2nd time
121836	End line
	New 101
1227	End 102
	202
123840	301
124350	402
1251	501
1256	602
13	701
1305	Stop record
1316	Restart ASICC.exe, freeze prog.
	Start record _02
1407	End of sea ice
1410	Climb
	Calibration ASIRAS, stop record
1506	Landing LYR
	Start up, problem starting EGI PC
1635	Taxi

1639	Take off LYR
	No contrast for KV, skipped
	Scanner issues, PC down
1744	Start record, open ocean
	Change to PC1, PC2 off line
	Calibration
1747	Start record
1751	Climb
	Network connection 2 off??? (no effect!)

1809	Run on PC1 only
1809	Calibration
1812	Record start _05, ice edge
1909	Icebergs at Nordøstrundingen
1915	Record start _06, Flade Isblink
1938	Stop record
	Calibration
1939	X runway
1945	Landing STN





<u>JD 110 20/4-2015 NRD – F – C - NRD</u>

Perfect weather St. Nord

1120 System start up

EGI start, navrdy after long time

1140 Taxi

1146 Take off NRD

1149 Calibration

1158 Start record _00

1203 Sheer zone

1238 Stop record

1239 F1 tear drop turn

1243 Record start _01

1255 Large open lead, partly refrozen (right side)

134255 Large refrozen lead

1346 Stop/start record _02

Very few leads F1-F2, 110 knts!

1459 F2, stop record

1504 Start record _03

1604 Stop/start record _04

162530 Fast ice

1640 Towards C2 (off line from F2)

Stop record

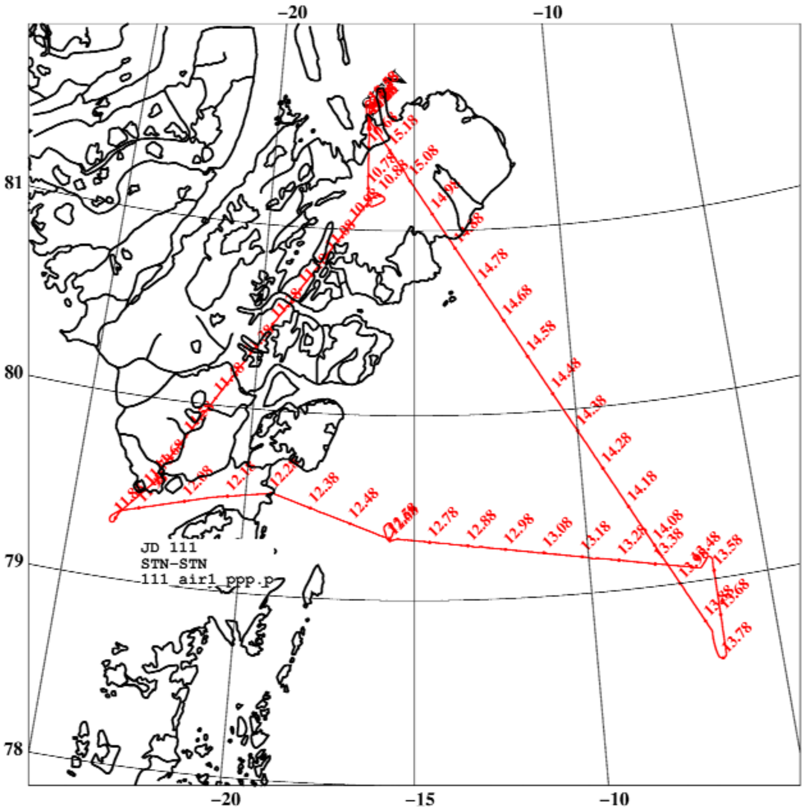
1648 Start record _05 for C2-C1

1650 C2

170030 Rwy, ASICC.exe freeze!

Bldg from two sides

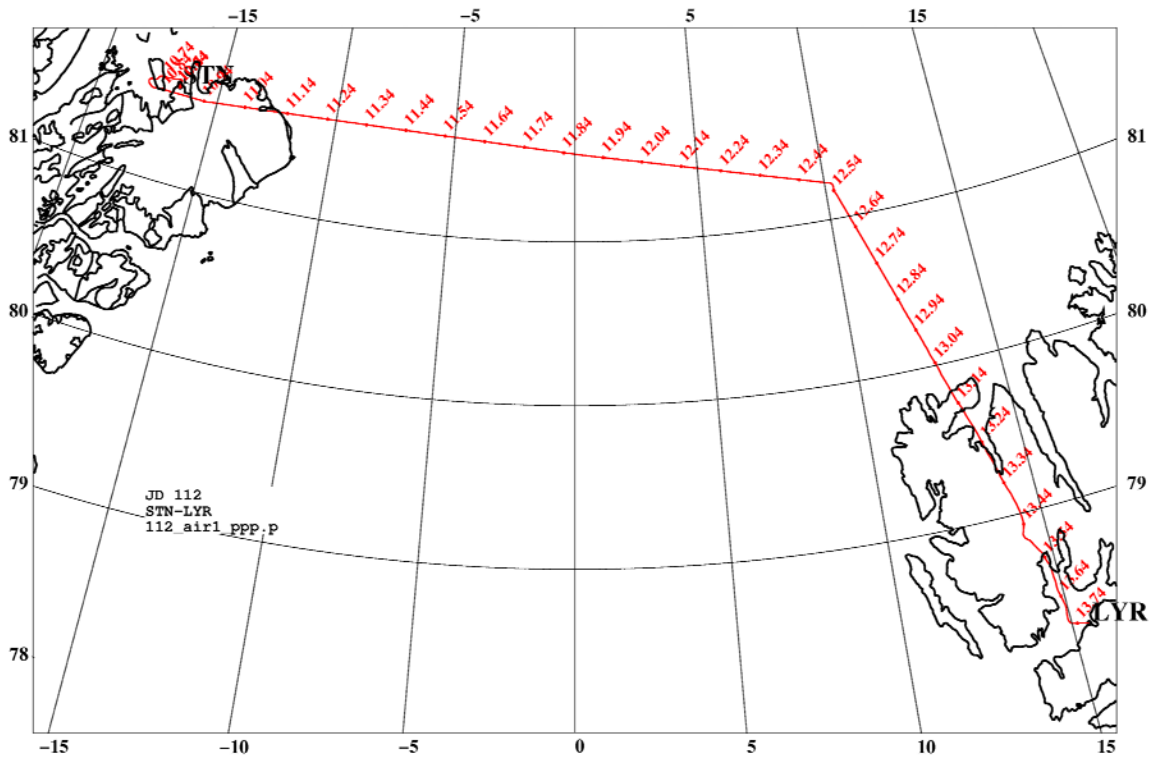
1714 Landing NRD



<u>JD 111 21/4-2015 NRD – 79F - TOB – ULS - NRD</u>

Perfect weather St. Nord

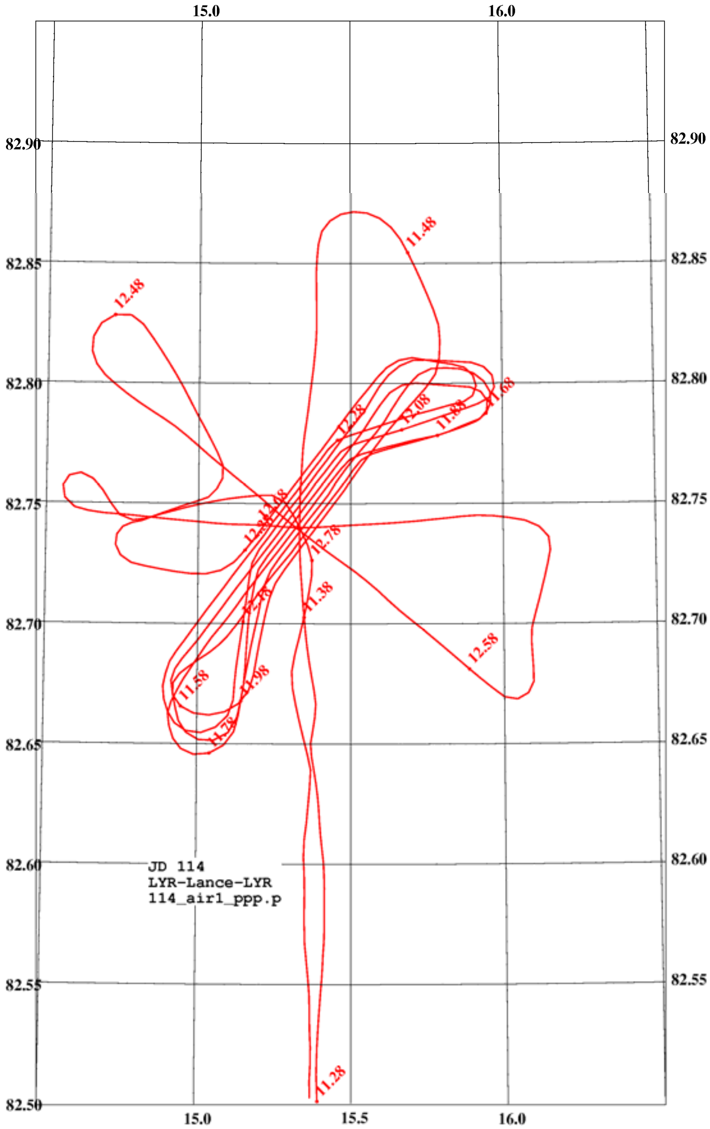
1000	System start up
	Reboot EGI pc
	EGI start, navrdy after long time
102430	Taxi
102840	Take off NRD
1036	Start ASIRAS, Calibration
1037	Start record _00
1048	P1, turn left
1101	Stop record
113900	AWI1
114010	AWI2
1146	Start record _01
115600	G9
1208	G8
121640	G7
121540	Glacier front
1218	Stop/start record _02
123400	TOB, turn left
123950	TOB from north
125800	End of fastice
1330	Stop/start record _03
1334	ULN
134010	U14
134230	Large floe
134530	ULS
1347	Stop record
1348	Start record _04
1350	Large floe again (right side)
1401	X line from TOB-ULN
1453	Stop/start record _05
1525	Calibration then off, to soon!
	Rwy
1531	Landing NRD



<u>JD 112 22/4-2015 NRD – P2 - LYR</u>

Perfect weather St. Nord

1015	System start up
	Reboot EGI pc
	EGI start
1030	navrdy (after long time)
103530	Taxi
1039	Take off NRD
1044	Start ASIRAS, Calibration
1046	Start record _00
105050	L6
105600	L5
1109	Stop/start record _01
	Coast line, fastice edge
1120	Door open
1200	Stop/start record _02
123030	P2
1252	End of sea ice, climb
	Stop record, copy data
1327	Calibration
	EGIcon off at some point!!!
1347	Landing



<u>JD 114 24/4-2015 LYR – Lance2 - LYR</u>

Sun and high wind at Lance, cloudy and light snow LYR

0915	System start up
0926	Taxi
092935	Take off LYR
0935	Start ASIRAS, Calibration
1025	Decend to survey from ice margin
1031	Start record _00 at 700m
1035	~1000 ft
1115	Re-calc pos for grid
1117	Stop/start record _01
1122	S->N Em line +- 5 nm from ship
1132	102 (start line WP)
1137	201
1143	302
1150	401
1157	502
1202	601
120830	702
121430	801
1221	902
1225	W->E EM line +-5 nm – off
123230	Ship on radar, line 90 degr to ship
123830	E->W EM line
1242	End of Lance survey
1243	Stop/start record _02 stopped
124630	Fly-by Lance
124730	Start record _03
1329	End of sea ice
1332	Stop record
1333	Calibration
1432	Start record _04
1435	Rwy
1442	Landing LYR

10. Appendix – Processed ASIRAS profiles

Following plots show all processed ASIRAS profiles. Each profile are plotted twice, and are shown next to each other using either the OCOG (left) or the TSRA (right) re-tracker. 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).

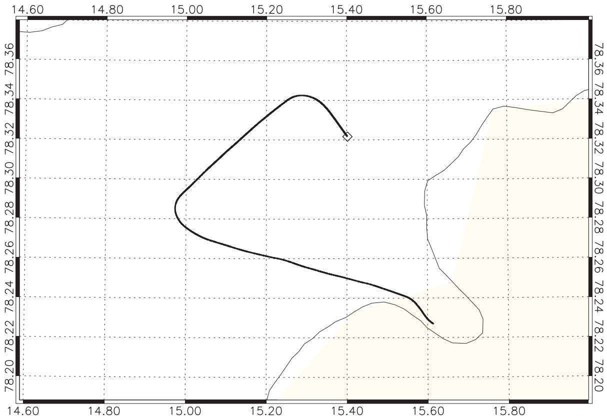
3. Rough indication of the heights as determined with the OCOG re-tracker plotted versus time of day in seconds.

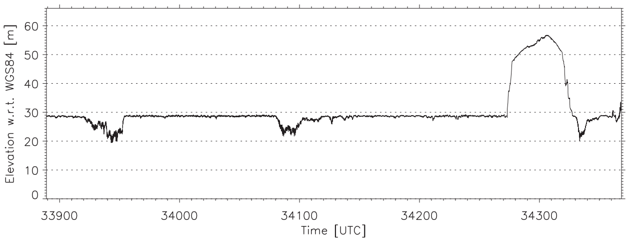
4. Info box with date, start and stop times in hour, minute, seconds, and in square brackets seconds of the day, acquisition mode etc.

It should be emphasized that the surface height determined by the OCOG re-tracker is a rough estimate and not a true height.

A150416_00

AS60A00_ASIWL1B040320150416T092449_20150416T093249_0001.DBL

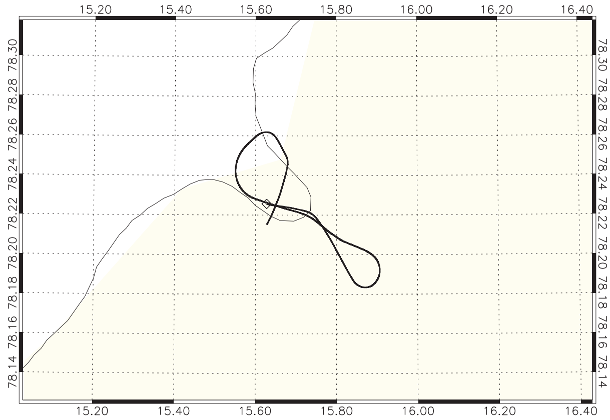


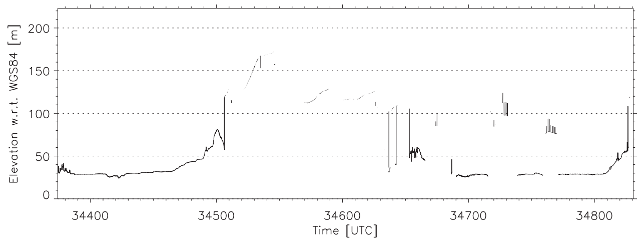


Date	2015-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	09:24:49 (33889)	**Aircraft**	BAS Twin Otter
Stop Time	09:32:48 (34368)	**Retracker**	OCOG
Distance	29.846 km	**INS Resolution**	50 Hz
Duration	00 h 07 m 59 s	**Processor Version**	0403

A150416_01

AS60A01_ASIWL1B040320150416T093254_20150416T094031_0001.DBL

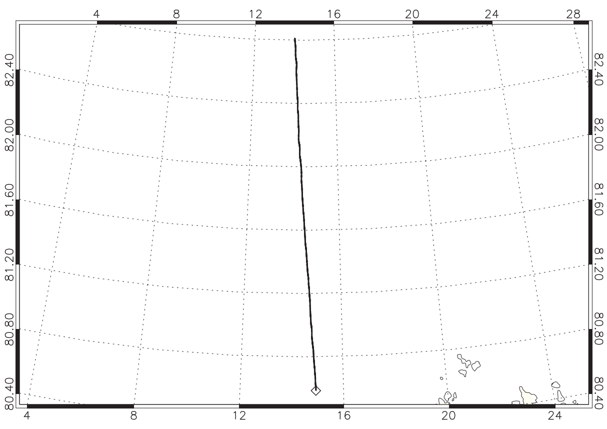


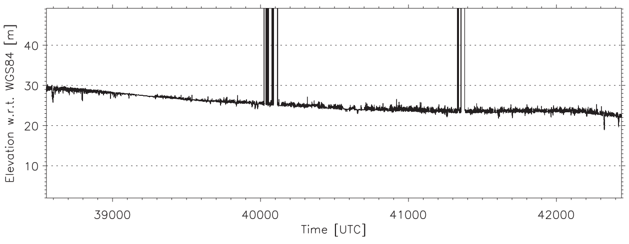


Date	2015-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	09:32:54 (34374)	**Aircraft**	BAS Twin Otter
Stop Time	09:40:30 (34830)	**Retracker**	OCOG
Distance	28.581 km	**INS Resolution**	50 Hz
Duration	00 h 07 m 37 s	**Processor Version**	0403

A150419_00

AS60A00_ASIWL1B040320150419T104233_20150419T114720_0001.DBL

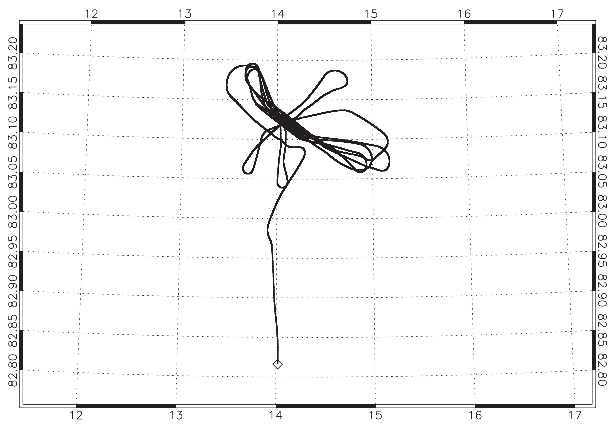


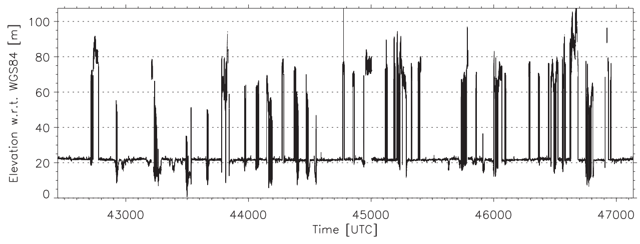


Date	2015-04-19	**Instrument Mode**	Adv. Low Altitude
Start Time	10:42:33 (38553)	**Aircraft**	BAS Twin Otter
Stop Time	11:47:19 (42439)	**Retracker**	OCOG
Distance	248.489 km	**INS Resolution**	50 Hz
Duration	01 h 04 m 47 s	**Processor Version**	0403

A150419_01

AS60A01_ASIWL1B040320150419T114724_20150419T130538_0001.DBL

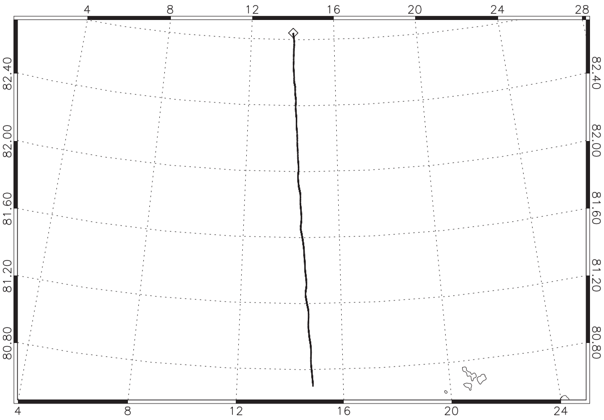


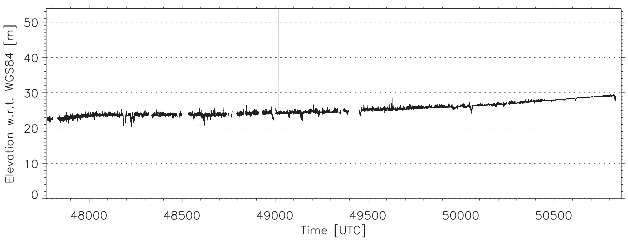


Date	2015-04-19	**Instrument Mode**	Adv. Low Altitude
Start Time	11:47:24 (42444)	**Aircraft**	BAS Twin Otter
Stop Time	13:05:37 (47137)	**Retracker**	OCOG
Distance	312.818 km	**INS Resolution**	50 Hz
Duration	01 h 18 m 14 s	**Processor Version**	0403

A150419_02

AS60A02_ASIWL1B040320150419T131609_20150419T140742_0001.DBL

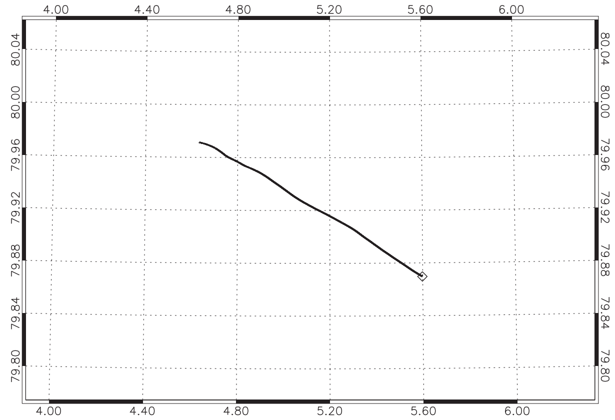


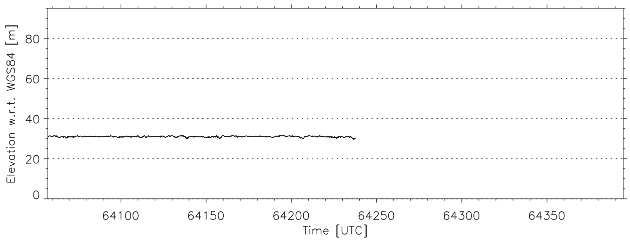


Date	2015-04-19	**Instrument Mode**	Adv. Low Altitude
Start Time	13:16:09 (47769)	**Aircraft**	BAS Twin Otter
Stop Time	14:07:41 (50861)	**Retracker**	OCOG
Distance	239.862 km	**INS Resolution**	50 Hz
Duration	00 h 51 m 33 s	**Processor Version**	0403

A150419_04

AS60A04_ASIWL1B040320150419T174737_20150419T175315_0001.DBL

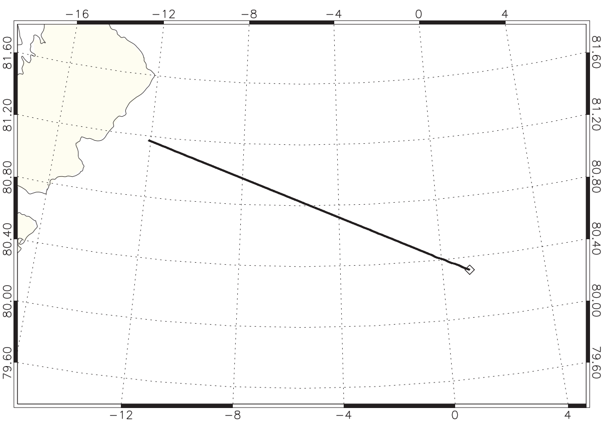


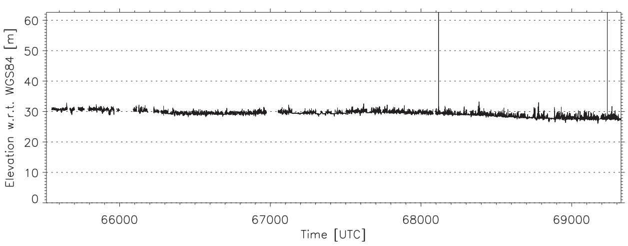


Date	2015-04-19	**Instrument Mode**	Adv. Low Altitude
Start Time	17:47:37 (64057)	**Aircraft**	BAS Twin Otter
Stop Time	17:53:14 (64394)	**Retracker**	OCOG
Distance	21.966 km	**INS Resolution**	50 Hz
Duration	00 h 05 m 38 s	**Processor Version**	0403

A150419_05

AS60A05_ASIWL1B040320150419T181154_20150419T191527_0001.DBL

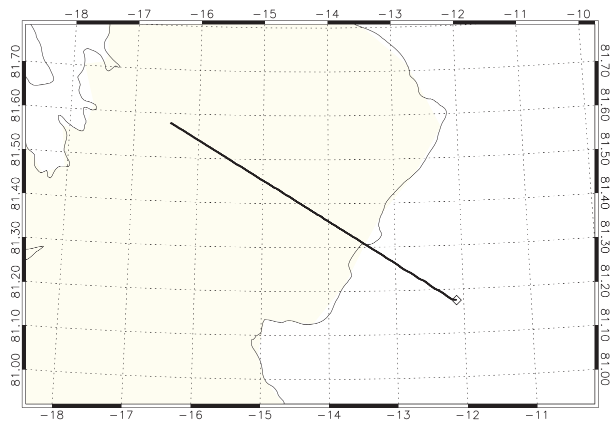


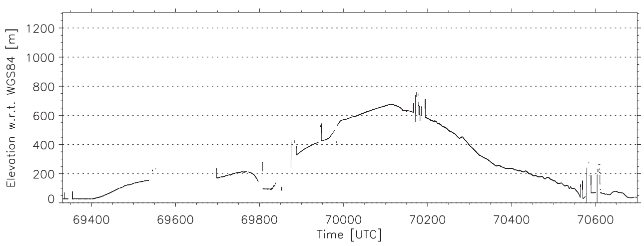


Date	2015-04-19	**Instrument Mode**	Adv. Low Altitude
Start Time	18:11:54 (65514)	**Aircraft**	BAS Twin Otter
Stop Time	19:15:27 (69327)	**Retracker**	OCOG
Distance	252.988 km	**INS Resolution**	50 Hz
Duration	01 h 03 m 33 s	**Processor Version**	0403

A150419_06

AS60A06_ASIWL1B040320150419T191531_20150419T193819_0001.DBL

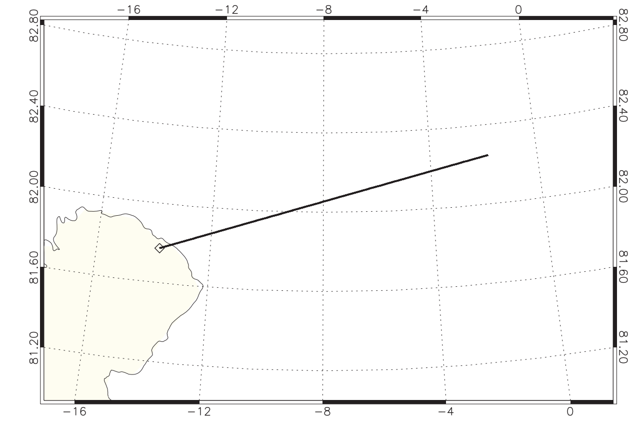


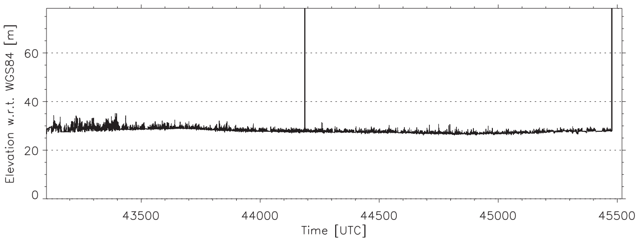


Date	2015-04-19	**Instrument Mode**	Adv. Low Altitude
Start Time	19:15:31 (69331)	**Aircraft**	BAS Twin Otter
Stop Time	19:38:18 (70698)	**Retracker**	OCOG
Distance	85.486 km	**INS Resolution**	50 Hz
Duration	00 h 22 m 48 s	**Processor Version**	0403

A150420_00

AS60A00_ASIWL1B040320150420T115822_20150420T123840_0001.DBL

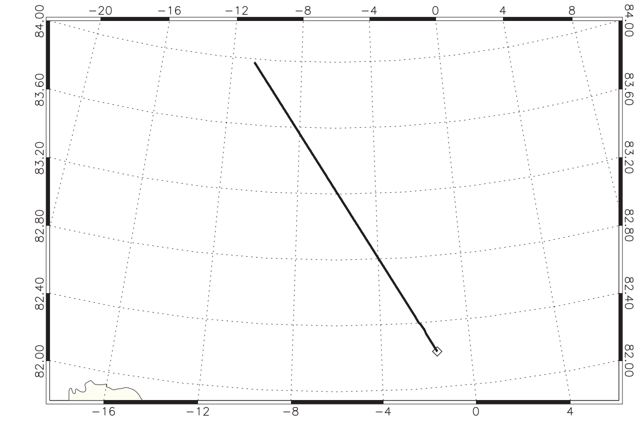


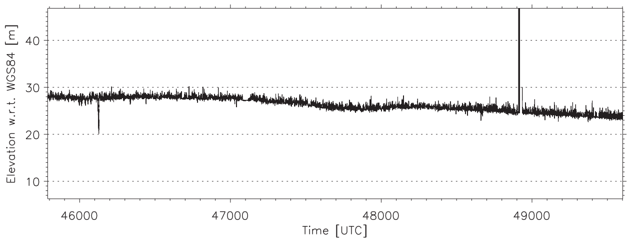


Date	2015-04-20	**Instrument Mode**	Adv. Low Altitude
Start Time	11:58:22 (43102)	**Aircraft**	BAS Twin Otter
Stop Time	12:38:39 (45519)	**Retracker**	OCOG
Distance	191.894 km	**INS Resolution**	50 Hz
Duration	00 h 40 m 18 s	**Processor Version**	0403

A150420_01

AS60A01_ASIWL1B040320150420T124308_20150420T134642_0001.DBL

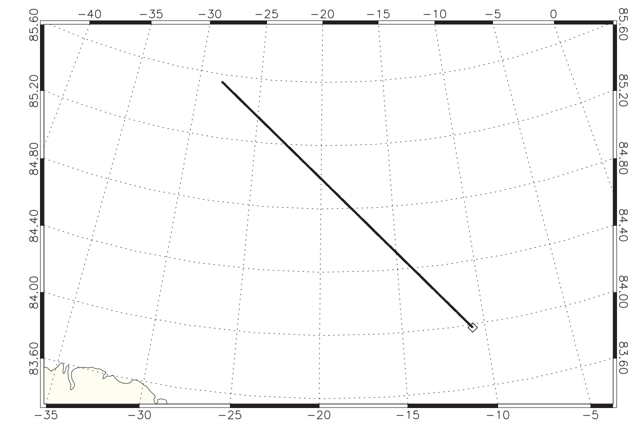


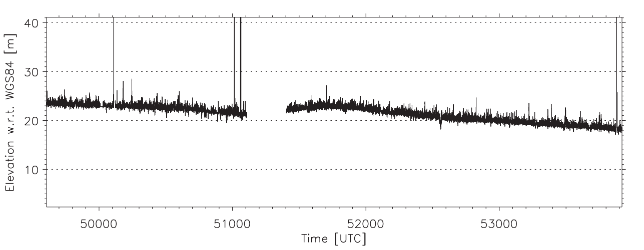


Date	2015-04-20	**Instrument Mode**	Adv. Low Altitude
Start Time	12:43:08 (45788)	**Aircraft**	BAS Twin Otter
Stop Time	13:46:41 (49601)	**Retracker**	OCOG
Distance	230.557 km	**INS Resolution**	50 Hz
Duration	01 h 03 m 34 s	**Processor Version**	0403

A150420_02

AS60A02_ASIWL1B040320150420T134646_20150420T145840_0001.DBL

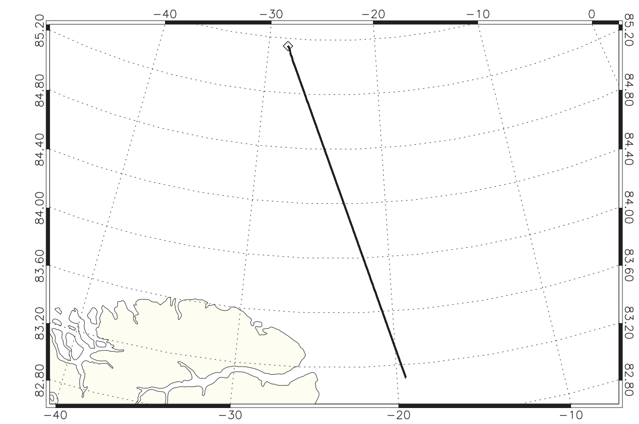


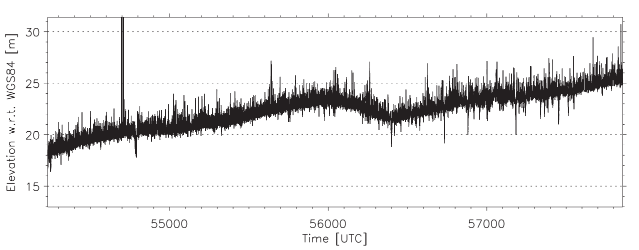


Date	2015-04-20	**Instrument Mode**	Adv. Low Altitude
Start Time	13:46:46 (49606)	**Aircraft**	BAS Twin Otter
Stop Time	14:58:39 (53919)	**Retracker**	OCOG
Distance	247.025 km	**INS Resolution**	50 Hz
Duration	01 h 11 m 53 s	**Processor Version**	0403

A150420_03

AS60A03_ASIWL1B040320150420T150351_20150420T160417_0001.DBL

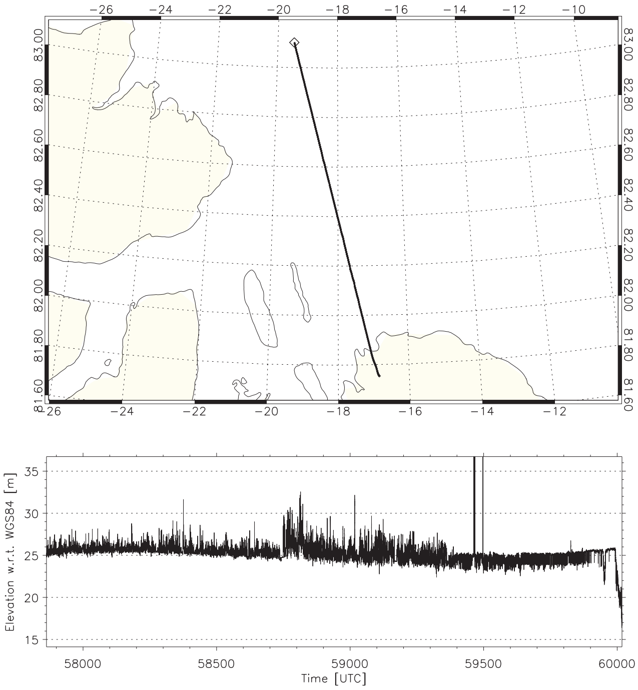




Date	2015-04-20	**Instrument Mode**	Adv. Low Altitude
Start Time	15:03:51 (54231)	**Aircraft**	BAS Twin Otter
Stop Time	16:04:16 (57856)	**Retracker**	OCOG
Distance	287.404 km	**INS Resolution**	50 Hz
Duration	01 h 00 m 26 s	**Processor Version**	0403

A150420_04

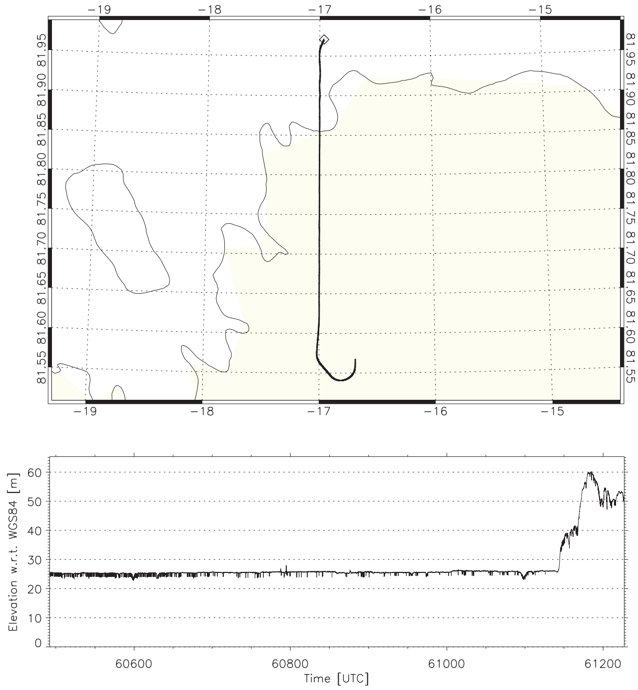
AS60A04_ASIWL1B040320150420T160423_20150420T164018_0001.DBL



Date	2015-04-20	**Instrument Mode**	Adv. Low Altitude
Start Time	16:04:23 (57863)	**Aircraft**	BAS Twin Otter
Stop Time	16:40:17 (60017)	**Retracker**	OCOG
Distance	155.003 km	**INS Resolution**	50 Hz
Duration	00 h 35 m 55 s	**Processor Version**	0403

A150420_05

AS60A05_ASIWL1B040320150420T164812_20150420T170027_0001.DBL



Date	2015-04-20	**Instrument Mode**	Adv. Low Altitude
Start Time	16:48:12 (60492)	**Aircraft**	BAS Twin Otter
Stop Time	17:00:26 (61226)	**Retracker**	OCOG
Distance	53.894 km	**INS Resolution**	50 Hz
Duration	00 h 12 m 15 s	**Processor Version**	0403

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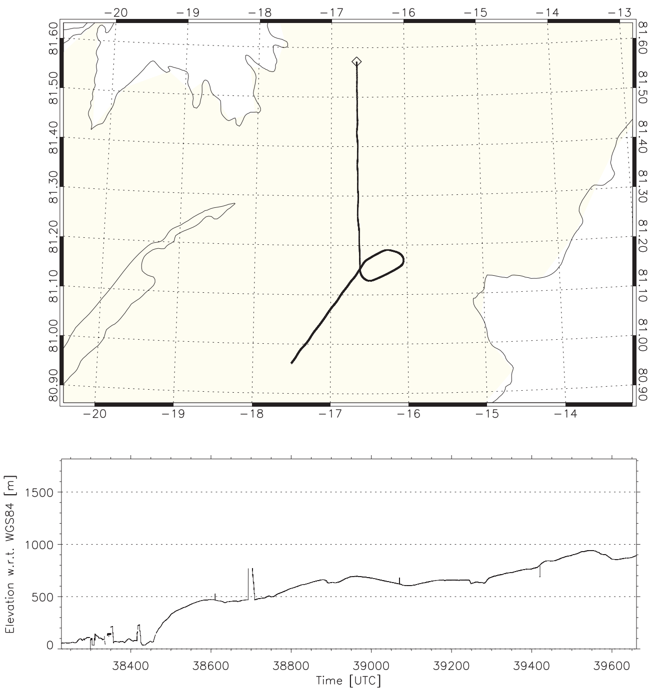

Date	2015-04-21	**Instrument Mode**	Adv. Low Altitude
Start Time	10:37:07 (38227)	**Aircraft**	BAS Twin Otter
Stop Time	11:01:01 (39661)	**Retracker**	OCOG
Distance	98.780 km	**INS Resolution**	50 Hz
Duration	00 h 23 m 54 s	**Processor Version**	0403

A150421_01

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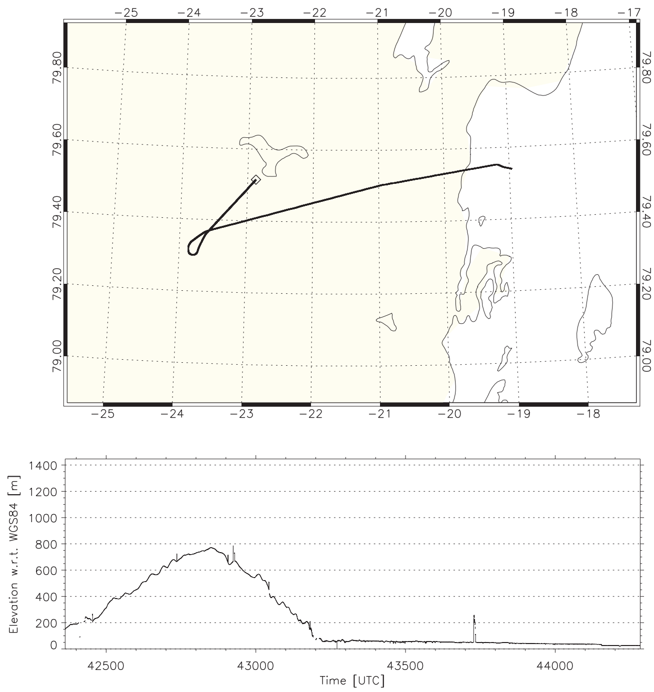

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Start Time	11:46:03 (42363)	**Aircraft**	BAS Twin Otter
Stop Time	12:18:03 (44283)	**Retracker**	OCOG
Distance	138.559 km	**INS Resolution**	50 Hz
Duration	00 h 32 m 01 s	**Processor Version**	0403

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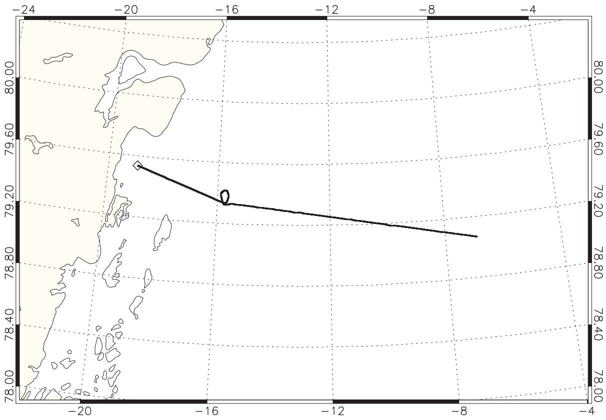

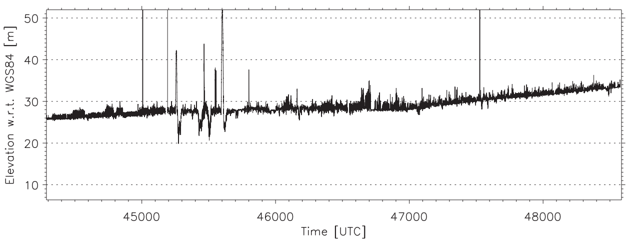

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Start Time	12:18:07 (44287)	**Aircraft**	BAS Twin Otter
Stop Time	13:29:46 (48586)	**Retracker**	OCOG
Distance	280.716 km	**INS Resolution**	50 Hz
Duration	01 h 11 m 39 s	**Processor Version**	0403

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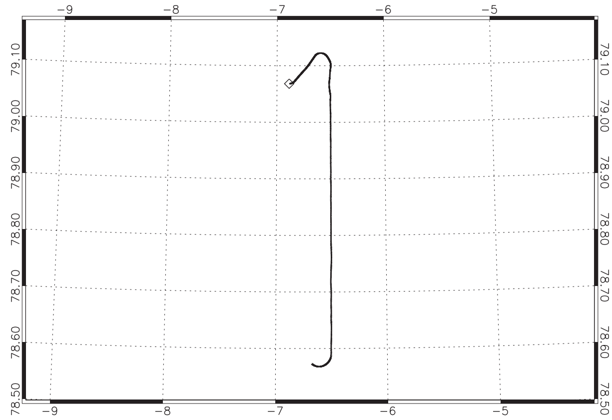

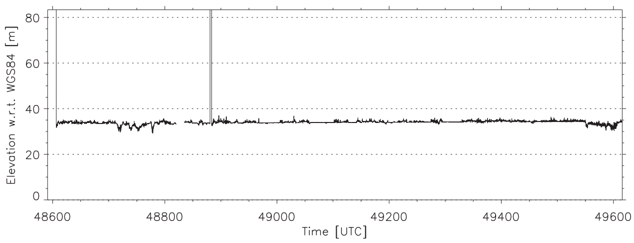

Date	2015-04-21	**Instrument Mode**	Adv. Low Altitude
Start Time	13:29:51 (48591)	**Aircraft**	BAS Twin Otter
Stop Time	13:46:55 (49615)	**Retracker**	OCOG
Distance	74.612 km	**INS Resolution**	50 Hz
Duration	00 h 17 m 05 s	**Processor Version**	0403

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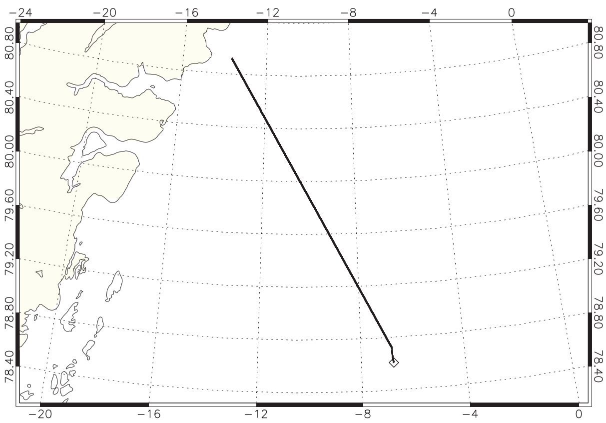

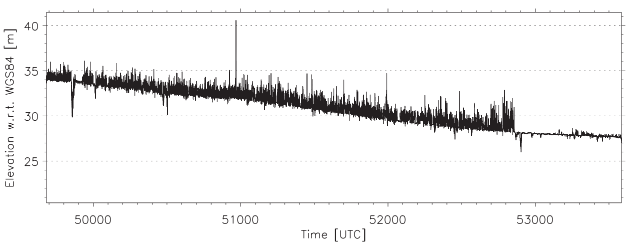

Date	2015-04-21	**Instrument Mode**	Adv. Low Altitude
Start Time	13:48:02 (49682)	**Aircraft**	BAS Twin Otter
Stop Time	14:53:04 (53584)	**Retracker**	OCOG
Distance	291.266 km	**INS Resolution**	50 Hz
Duration	01 h 05 m 03 s	**Processor Version**	0403

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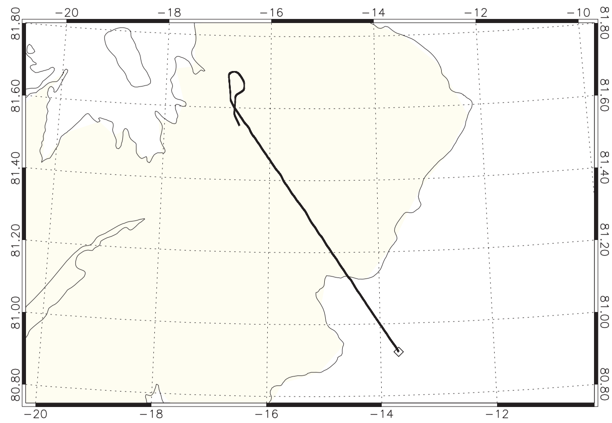

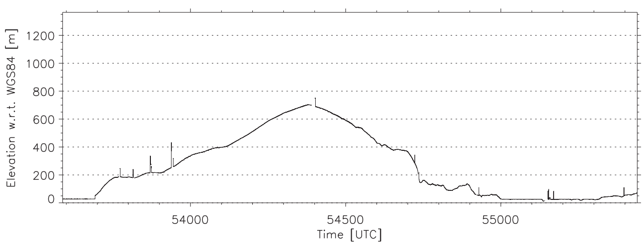

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Start Time	14:53:08 (53588)	**Aircraft**	BAS Twin Otter
Stop Time	15:23:59 (55439)	**Retracker**	OCOG
Distance	123.505 km	**INS Resolution**	50 Hz
Duration	00 h 30 m 51 s	**Processor Version**	0403

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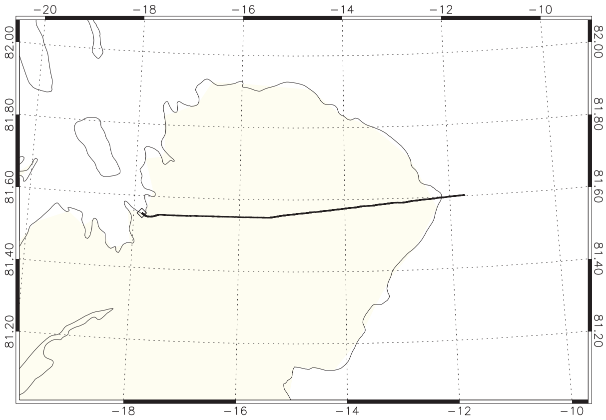

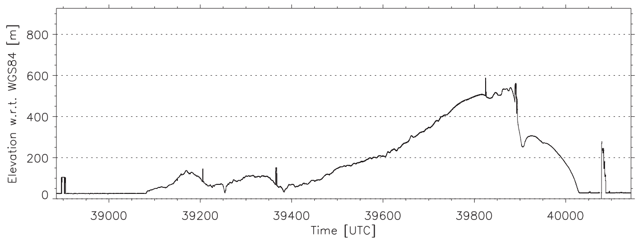

Date	2015-04-22	**Instrument Mode**	Adv. Low Altitude
Start Time	10:48:05 (38885)	**Aircraft**	BAS Twin Otter
Stop Time	11:09:02 (40142)	**Retracker**	OCOG
Distance	100.956 km	**INS Resolution**	50 Hz
Duration	00 h 20 m 58 s	**Processor Version**	0403

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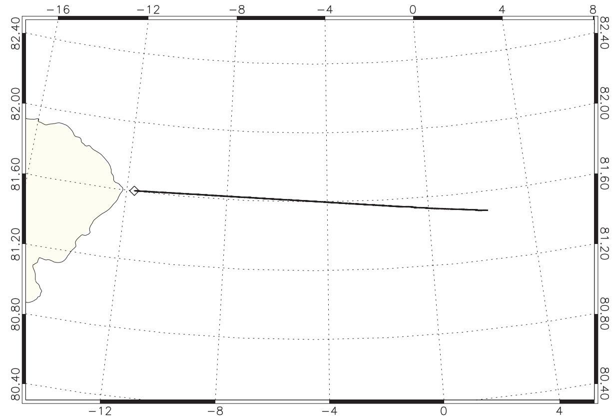

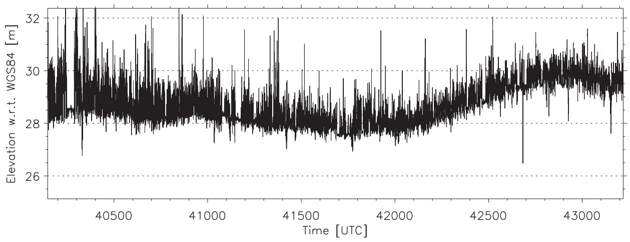

Date	2015-04-22	**Instrument Mode**	Adv. Low Altitude
Start Time	11:09:06 (40146)	**Aircraft**	BAS Twin Otter
Stop Time	12:00:18 (43218)	**Retracker**	OCOG
Distance	229.451 km	**INS Resolution**	50 Hz
Duration	00 h 51 m 13 s	**Processor Version**	0403

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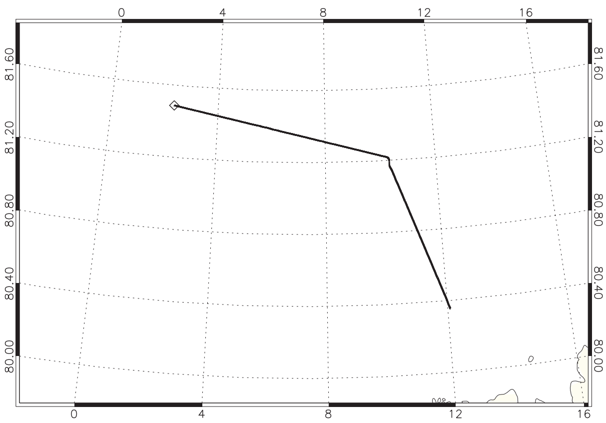

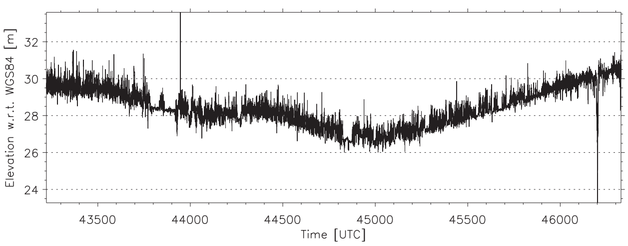

Date	2015-04-22	**Instrument Mode**	Adv. Low Altitude
Start Time	12:00:22 (43222)	**Aircraft**	BAS Twin Otter
Stop Time	12:52:08 (46328)	**Retracker**	OCOG
Distance	237.457 km	**INS Resolution**	50 Hz
Duration	00 h 51 m 46 s	**Processor Version**	0403

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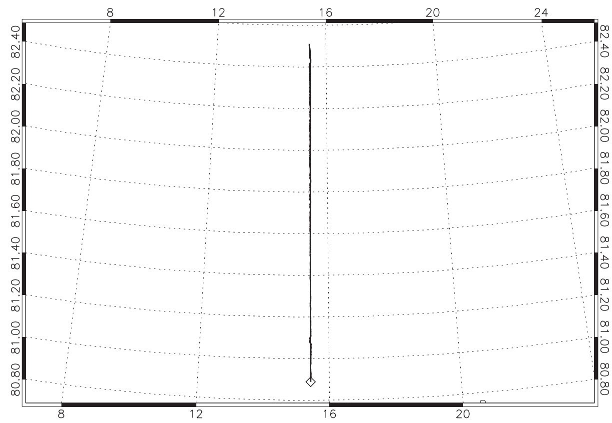

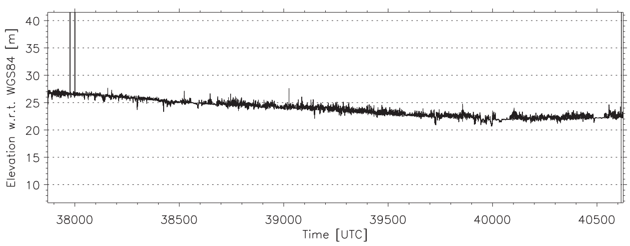

Date	2015-04-24	**Instrument Mode**	Adv. Low Altitude
Start Time	10:31:10 (37870)	**Aircraft**	BAS Twin Otter
Stop Time	11:17:05 (40625)	**Retracker**	OCOG
Distance	180.802 km	**INS Resolution**	50 Hz
Duration	00 h 45 m 55 s	**Processor Version**	0403

A150424_01

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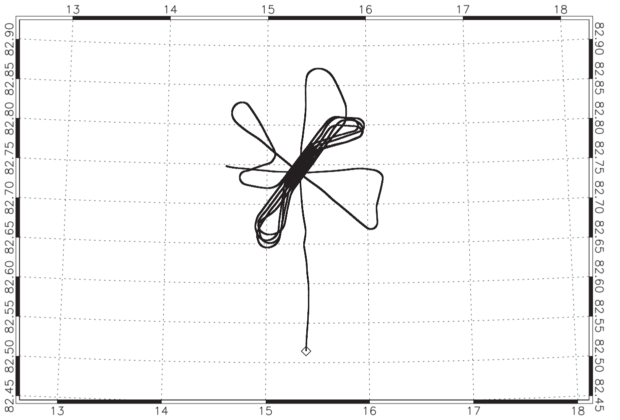

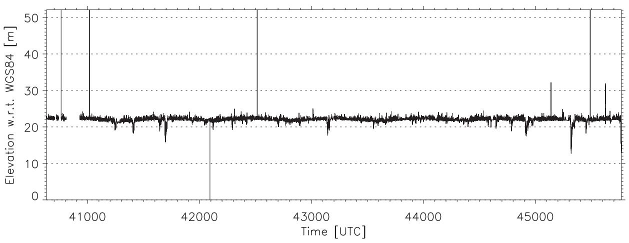

Date	2015-04-24	**Instrument Mode**	Adv. Low Altitude
Start Time	11:17:11 (40631)	**Aircraft**	BAS Twin Otter
Stop Time	12:42:47 (45767)	**Retracker**	OCOG
Distance	336.206 km	**INS Resolution**	50 Hz
Duration	01 h 25 m 37 s	**Processor Version**	0403

A150424_02

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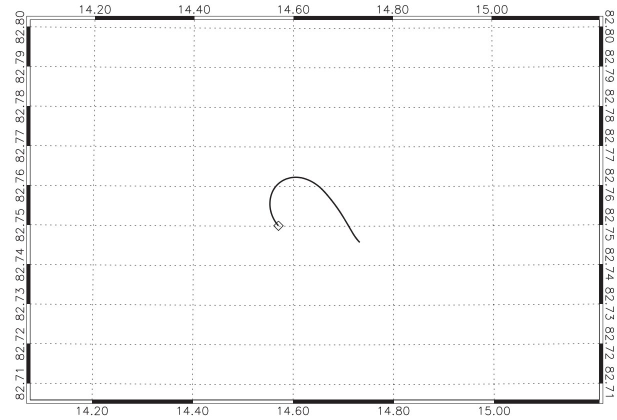

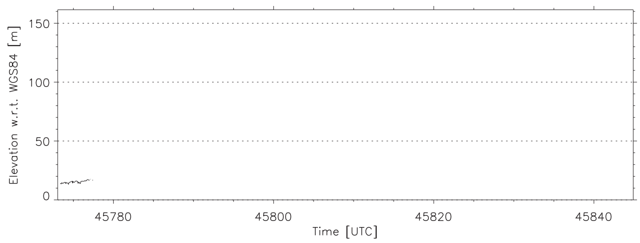

Date	2015-04-24	**Instrument Mode**	Adv. Low Altitude
Start Time	12:42:53 (45773)	**Aircraft**	BAS Twin Otter
Stop Time	12:44:04 (45844)	**Retracker**	OCOG
Distance	4.499 km	**INS Resolution**	50 Hz
Duration	00 h 01 m 12 s	**Processor Version**	0403

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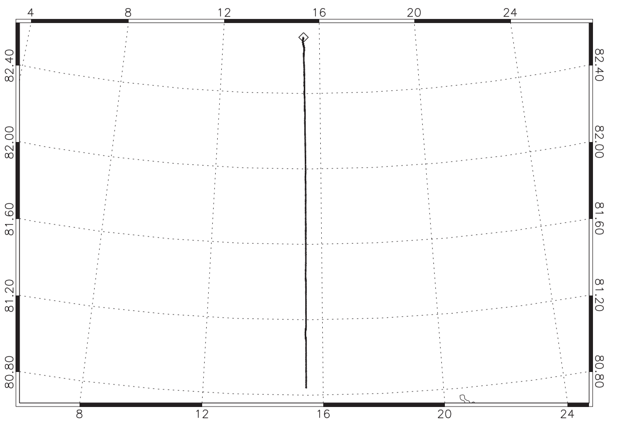

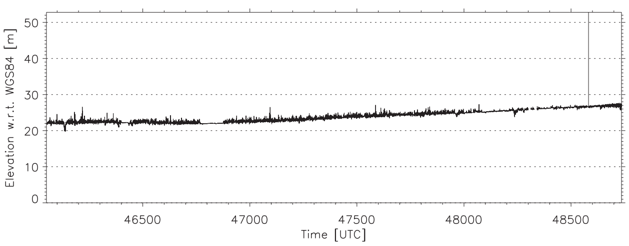

Date	2015-04-24	**Instrument Mode**	Adv. Low Altitude
Start Time	12:47:30 (46050)	**Aircraft**	BAS Twin Otter
Stop Time	13:32:15 (48735)	**Retracker**	OCOG
Distance	207.519 km	**INS Resolution**	50 Hz
Duration	00 h 44 m 46 s	**Processor Version**	0403

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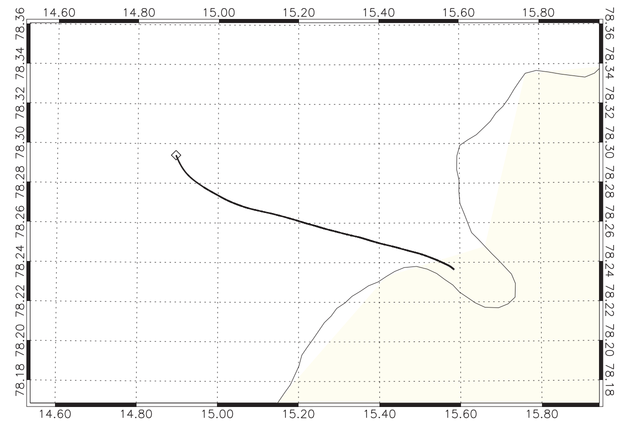

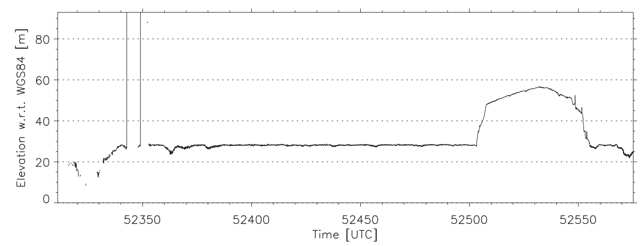

Date	2015-04-24	**Instrument Mode**	Adv. Low Altitude
Start Time	14:31:51 (52311)	**Aircraft**	BAS Twin Otter
Stop Time	14:36:15 (52575)	**Retracker**	OCOG
Distance	17.423 km	**INS Resolution**	50 Hz
Duration	00 h 04 m 24 s	**Processor Version**	0403

ESA GNSS FinExp 2015

Additional airborne activity in the Baltic Sea during the SPIR campaign

Data collection and processing report

H. Skourup, R. S. Ladkin, J. Wilkinson, R. Forsberg, S. M. Hvidegaard and V. Helm

National Space Institute (DTU Space)
Technical University of Denmark

Version 2.0
April 2018

EUROPEAN SPACE AGENCY CONTRACT REPORT

ESA Contract No. 4000110600/14/NL/FF/lf/CCN2

ESA GNSS FinExp 2015

Additional airborne activity in the Baltic Sea during the SPIR campaign

Authors:
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ESA STUDY CONTRACT REPORT

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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 sea surface heights in the Baltic Sea to provide ground-truth for the Software PARIS Interferometric Receiver (SPIR) experiment. The airborne campaign was coordinated by the National Space Institute (DTU Space) and British Antarctic Survey (BAS) using the BAS Twin Otter (VP-FAZ).

The GNSS FinExp 2015 was carried out on April 29 – May 3, 2015, from Malmi airport in Helsinki, Finland, following an Arctic campaign to map the sea ice and land ice topography, as part of the EU FP7 project ICE-ARC (Ice, Climate, Economics – Arctic Research on Change), using the same aircraft and instrument installation.

One near coincident flight with the SPIR instrument installed in a Skyvan belonging to the University of Aalto, Finland, was possible and obtained on May 3, 2015. The ASIRAS and ALS data was found to be of high quality with vertical accuracy of less than 10 cm. In general, the ASIRAS and ALS elevations show good agreement over open, using the OCOG re-tracker.

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:
H. Skourup, R. S. Ladkin, J. Wilkinson, R. Forsberg, S. M. Hvidegaard and V. Helm

<table>
<tr><td>NAME OF ESA STUDY MANAGER
Tânia Casal
Mission Science Division
Validation Campaigns - ESTEC</td><td>ESA BUDGET HEADING</td></tr>
</table>

Contents

1 Introduction

The objective of the GNSS FinExp 2015 is to provide ground-truth for the Software PARIS Interferometric Receiver (SPIR) experiment through the collection and analysis of coordinated airborne measurements of the sea surface height (SSH) with ESA airborne Ku-band radar (ASIRAS) and coincident airborne laser scanner (ALS).

The GNSS FinExp 2015 and SPIR campaigns support the ESA GEROS ISS scientific experiment, an innovative concept which will exploit reflected signals from GNSS satellites at L-band to measure key parameters of the ocean surface relevant to characterize climate change.

The airborne campaign was coordinated by the National Space Institute (DTU Space) and British Antarctic Survey (BAS) using the BAS Twin Otter (VP-FAZ). The GNSS FinExp 2015 campaign was following an Arctic campaign to map the sea ice and land ice topography as part of the EU FP7 project ICE-ARC (Ice, Climate, Economics – Arctic Research on Change) using the same aircraft and instrument installation.

Figure 1: The Finish Skyvan (left) and BAS Twin Otter (right) in Malmi airport, Helsinki.

2 Summary of operation

The GNSS FinExp 2015 was carried out on April 29 – May 3, 2015, from Malmi airport (airport code: EFHF) in Helsinki, Finland. The flights were coordinated to collect observations of the sea surface height coincident with the SPIR experiment.

The instruments were installed in two different aircrafts; where the ASIRAS and ALS were installed in the BAS Twin Otter the SPIR instrument was installed in a SC7 Skyvan belonging to the Laboratory of Space Technology, University of Aalto, Helsinki, Finland.

Due to problems with the SPIR instrument and aircraft maintenance of the Skyvan only one out of two planned flights were possible using both aircrafts. The flight took place on May 3rd in the afternoon. An overview of the ground track is presented in Figure 2, and the operator log applied in Appendix 1. All the ASIRAS data were acquired in Low Altitude Mode (LAM) with low along-track resolution (LAMa). This allows the aircraft to maintain an altitude of 1,000 ft, which is within the operational range of the ALS System. The SPIR instrument on the other hand needs a larger range, and the Skyvan maintained a flight altitude of 10,000 ft, allowing almost coincident data acquisition from the various instruments.

The airborne team consisted of Henriette Skourup (DTU Space) and Russell S. Ladkin (BAS).

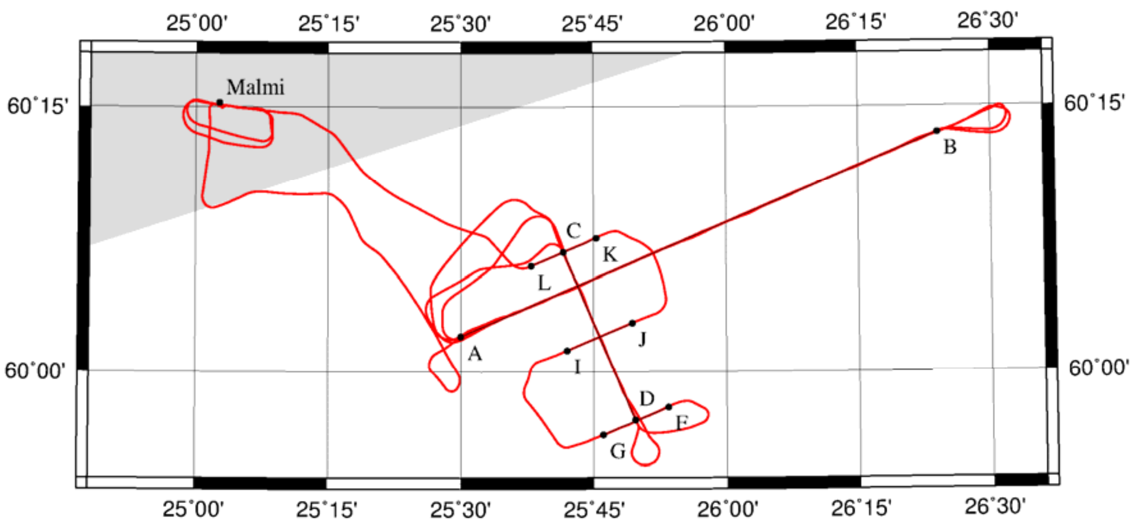


Figure 2: Overview of the flight tracks (red lines) from the FinExp 2015 airborne campaign. The waypoints are added to the map and the flight pattern followed; A-B, B-A, C-D, D-C, A-B, B-A, C-D, F-G, I-J, K-L.

3 Hardware installation

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

- ESA ku-band interferometric radar ASIRAS
- BAS Airborne Laser Scanner (ALS) of the type Riegl LMS Q-240i-80
- One NovAtel GPS kindly loaned by AWI to support ASIRAS operation
- Two geodetic dual-frequency GPS receivers (Trimble 5700, Javad delta) together with a Javad AT4; a 4 antenna array for backup attitude and velocity determination. The Trimble and AT4 receivers were connected to the aft antenna, whereas the stand alone Javad delta was connected to the front antenna.
- An Inertial navigation system (INS) of the type Honeywell H-764G (Primary INS)
- An INS of the type OxTS Inertial+2 (Backup INS)

Auxiliary instruments:

- Meteorological Airborne Survey Instrumentation (MASIN)
- DSLR Camera (Canon EOS 7D)

The instruments were mounted in the aircraft and tested in Cambridge before the departure for the ICE-ARC campaign. The lever arms from GPS antenna to ASIRAS and ALS reference points are given in Table 1, and the hardware installation can be seen in Figure 3 and 4.

Table 1: The dx, dy and dz offsets for the lever arm from the GPS antenna to the origin of the laser scanner, and to the back centre of the ASIRAS antenna.

To laser scanner	**dx (m)**	**dy (m)**	**Dz (m)**
from GPS front antenna	- 4.76	- 0.31	+ 1.58
to ASIRAS antenna	**dx (m)**	**dy (m)**	**dz (m)**
From GPS front antenna	-5.85	-0.31	+1.95

Figure 3: Instrument installation in the camera bay below the floor in the Twin Otter cabin; ALS (left), OxTS INS (middle right) and Trimble GPS receiver (lower right). Note ALS and OxTS INS axis are mounted along aircraft centre line.

Figure 4: Picture taken from the back of the Twin Otter. ASIRAS instrument is in the aft rack and control computers in the other rack. The Honeywell INS is mounted under the seat.

4 Data handling

4.1 GPS and INS data

The position of the aircraft is found from kinematic solutions of the GPS data collected during flight using GrafNav 8.30 software. Two methods can be used for post-processing of GPS data, kinematic differential processing and precise point positioning. 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.

A GPS base station of type Javad Delta coupled with a TopCon PG-A1 antenna, was placed next to the apron in the airport logging with 1 Hz. The exact position of the base station was found using the online service AUSPOS (http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos).

In this example, the differential solution shows the best result with a vertical standard deviation of less than 7 cm and a horizontal standard deviation of less than 5 cm, see Figure 5.

The position from the GPS solution is combined with attitude information (pitch, roll and heading) from the inertial navigation system. Here is only used data from the primary INS Honeywell (H-764G), as the attitude of the backup instrument (OxTS) is found to have degraded accuracy during acceleration, which includes turns and rapid changes of altitude (Skourup et al, 2012). The raw data recovered from the Honeywell was sampled at 10 Hz and merged with the GPS solution 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.

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

In this way a smooth GPS-INS solution is obtained, which can be used for geolocation of radar and laser altimetry observations. Final solutions of GPS and INS data are packed in special ESA format as defined in Cullen (2010). List of final files are provided in Appendix 4.

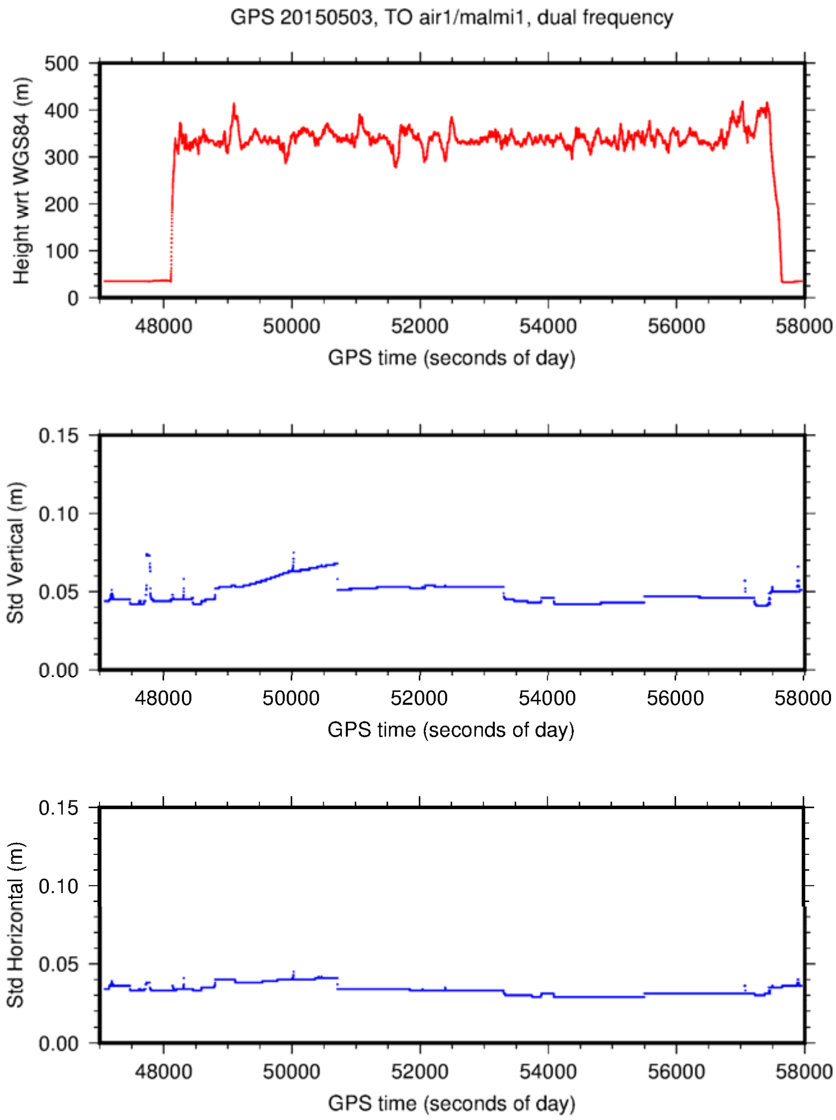


Figure 5: Kinematic GPS solution.

4.2 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, using a data rate of 250 pulses per line. This corresponds to a horizontal resolution of 1 m x 1 m at a flight height of 300 m and a ground speed of 250 kph. The across-track swath width is roughly 2/3 of the flight height, and the vertical accuracy is less than 10 cm depending primarily on uncertainties in the kinematic GPS-solutions. The raw logged files with start /stop times are listed in Appendix 2.

Calibration of ALS misalignment angles between GPS and INS can be estimated by analysing crossings of ALS tracks, and minimizing the height difference in the crossing points. Additionally the calibration is tuned to ground control points from overflights of a building from different directions, where the positions of the corners are known with high precision from GPS measurements. Such calibrations were surveyed during the ICE-ARC campaign and resulting misalignment angles are presented in Table 2. As the offset angles are found to be constant throughout the campaign, as would be expected from the installation where the laser scanner is mounted in the protected camera bay below the floor, the same angles are used for the GNSS FinExp 2015 campaign. In a similar manner time synchronization between ALS and INS/GPS are tested using buildings with known position near Malmi airport, see Figure 6.

Table 2: Misalignment angles between GPS and INS in degrees.

	Pitch	Roll	Heading
Misalignment angles	0.35	-0.60	-0.40

The processing of ALS data is performed by combining GPS/INS navigation information with laser range measurements, using the geometry of the installation (Table 1) and information from the calibration (Table 2). The final processed data has been manually filtered for outliers and clouds, and is presented in Figure 7.

The accuracy of the ALS point cloud data depends on the sum of inaccuracies in the GPS positioning (main error source), attitude determination from combined GPS and INS, range observation together with the calibration. The statistics from survey crossings (bias and standard deviation) can be used as a guideline to the accuracy of the observations. As the survey crossings of the GNSS FinExp 2015 campaign are primarily obtained over the ocean, where the width of the ALS is limited, these crossings are not optimal for estimation of the accuracy. The accuracy during the ICE-ARC campaign was found to be about 10 cm. As the accuracy of the GPS solution during GNSS FinExp 2015 is much better than the GPS accuracy obtained during the ICE-ARC campaign, we conclude that the vertical accuracy of the ALS is less than 10 cm.

Processed data comes as geo-located point clouds, in lines of width ~500 m at full resolution 1m x 1m, 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 data is packed in netcdf4 format and final file is listed in Appendix 4.

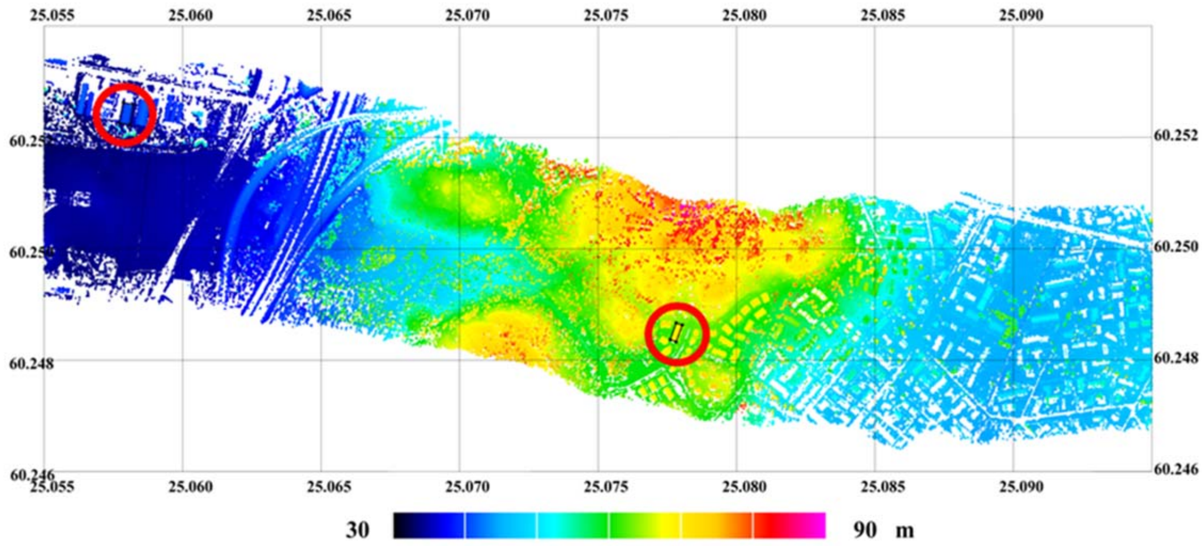


Figure 6: Buildings near Malmi airport with known positions marked by red circles.

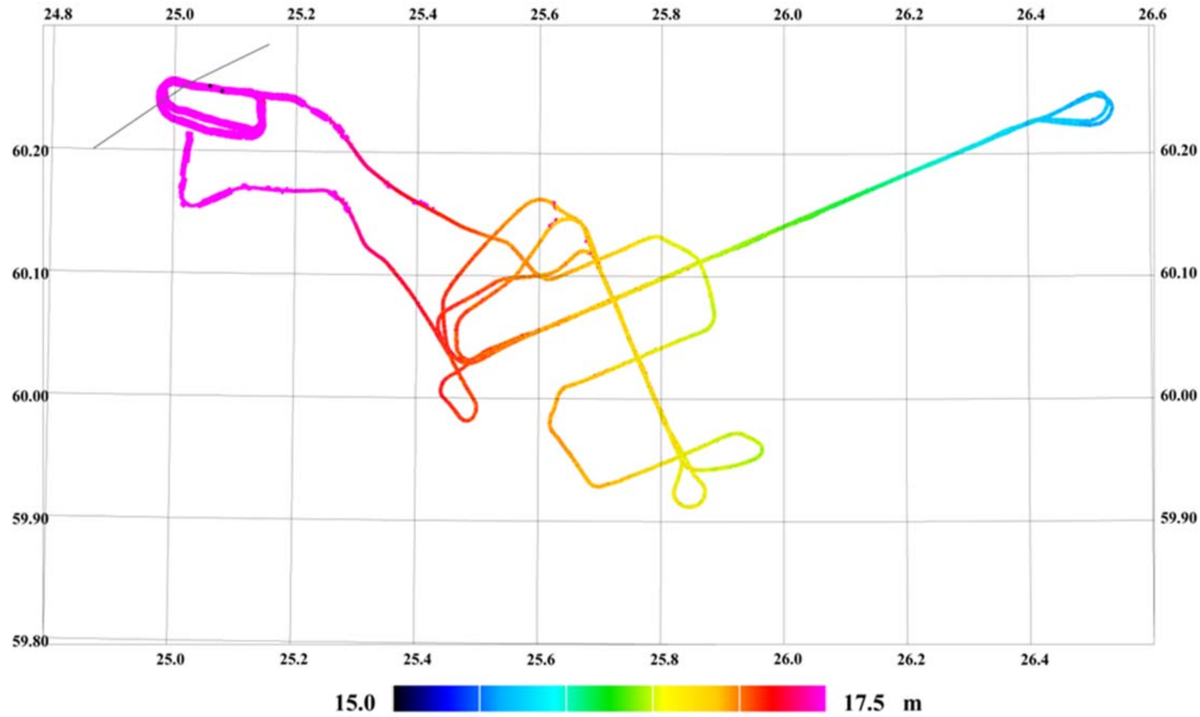


Figure 7: Processed ALS elevations w.r.t. WGS-84 reference ellipsoid.

4.3 ASIRAS

The ASIRAS radar operates at 13.5 GHz with footprint size 3 m along-track and 10 m across-track in Low Altitude mode with low resolution (LAM-A) at a standard flight height of 1,000 ft. An overview of the acquired ASIRAS log-files together with start/stop times, range window and number of pulses are listed in Appendix 3. 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 L1b ASIRAS data includes re-tracked sea surface heights using the Offset Center of Gravity (OCOG) re-tracker, which might not be the most optimal, but a suitable re-tracker for tracking sea surface heights over the ocean (Jain et al., 2015). A summary of the final processed files together with plots of each profile is given in Appendix 4 and 5, respectively. Level 1B data is delivered in binary, big endian format as described by Cullen (2010).

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 re-tracker 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. Two successive runway overflights were performed in Malmi airport, see Figure 8 upper plot. Unfortunately the wet runway reflects most of the laser signal away from nadir, and thus no signal are reflected back to the ALS, see Figure 8 middle left, where coincident observations of both ASIRAS and ALS are marked by red dots. The surface elevations of ASIRAS (red) and ALS (green) is shown in Figure 8 lower plot. The statistical distribution of the offset between the elevations is shown in the histogram. The mean offset between the elevations is -3.46 m with standard deviation 0.06 m.

An example of coincident ASIRAS and ALS observations, are given in Figure 9 along a sub-section of flight line A-B. The full ALS scan is shown in the upper plot together with the ASIRAS observations plotted on top (black line). Ocean waves with amplitude about 50-75 cm are clearly visible in the scanner elevations. The ASIRAS (red) and ALS (green) elevations referenced to the WGS-84 ellipsoid are shown in Figure 9 middle plot, where each ALS elevation is an average of the ALS observations within a diameter of 3 m (corresponding to the ASIRAS along-track footprint size) centered at the ASIRAS nadir position. ASIRAS elevations have been corrected for the offset found from the runway overflight. A zoom in lower right demonstrates the performance of the OCOG re-tracker over ocean. As the ALS and ASIRAS is expected to reflect at the same surface over the ocean, a histogram showing the distribution of the differences between ALS and ASIRAS elevations are included in the Figure. The mean difference is 3.48 m with standard deviation 0.14 m, which is within the accuracy of the measurements over the runway, the larger standard deviation caused by the ocean waves.

In the above analysis the ASIRAS surface elevations are not reliable for roll-angles larger than ±1.5° degrees, due to blurring of the waveforms. Thus, measurements at roll angles larger than 1.5° and less than -1.5° degrees has been discarded.

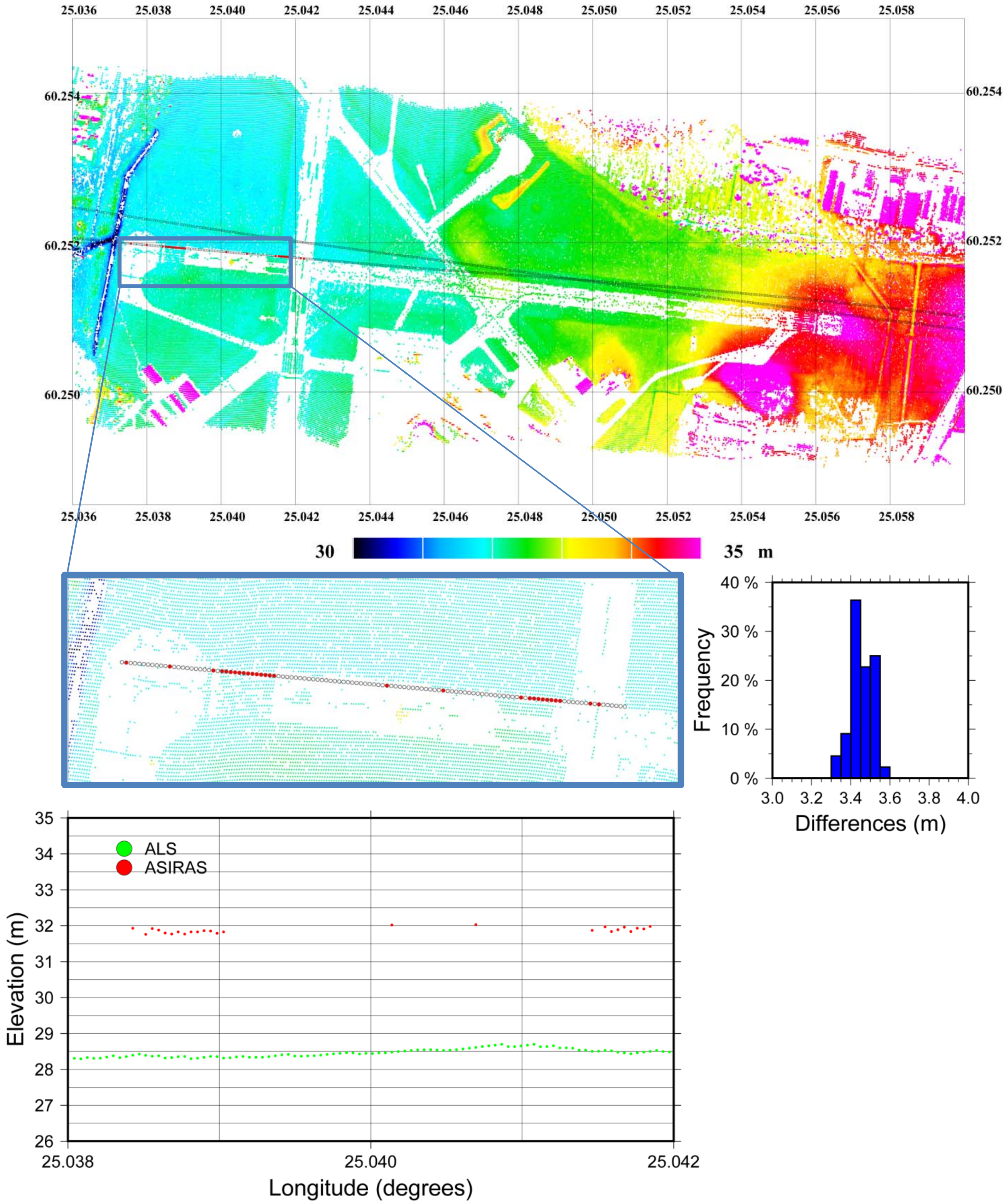


Figure 8: Overview of runway overflights at Malmi airport, Helsinki, Finland.

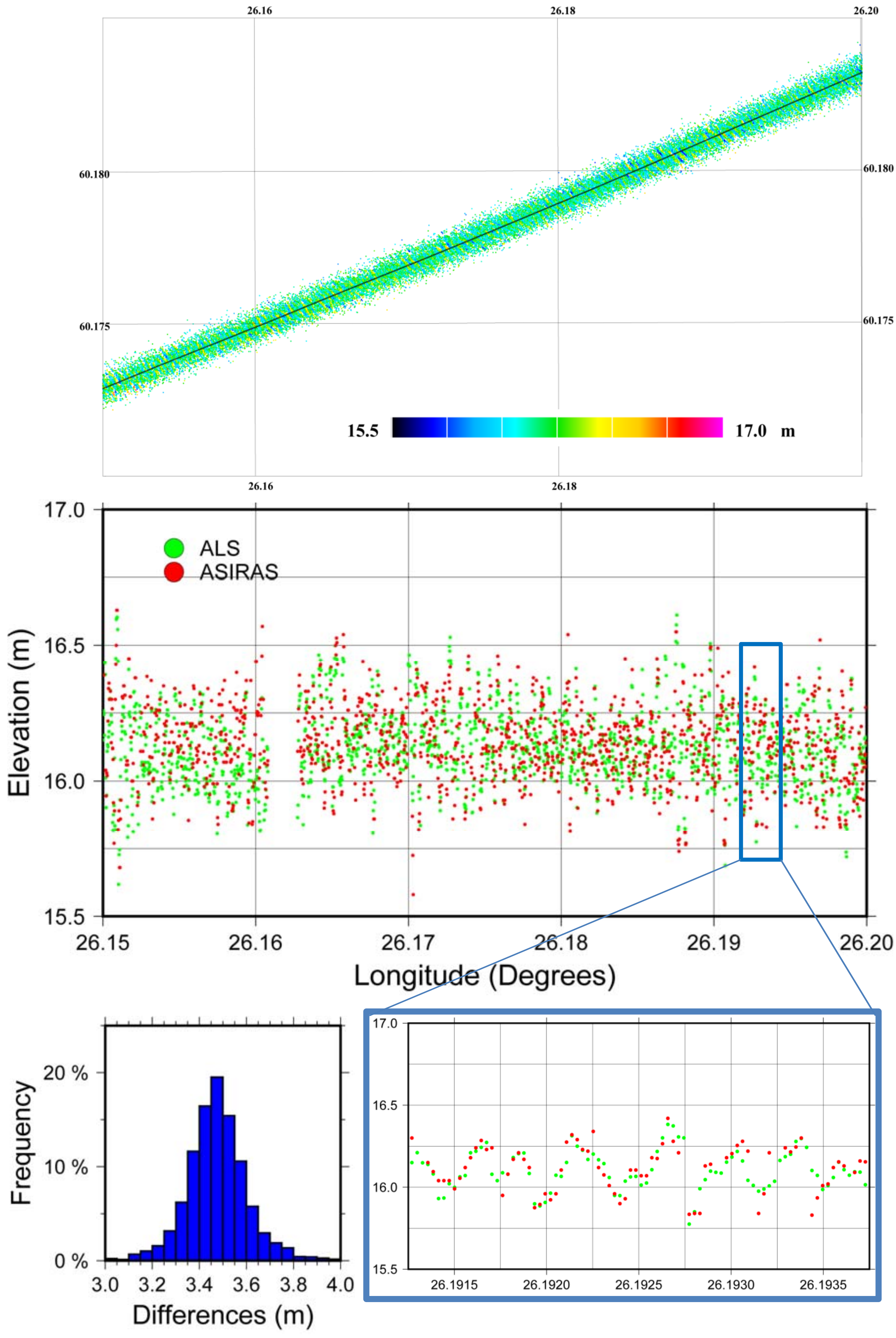


Figure 9: Ocean waves are visible in the elevations along the sub-section of the flight line; A-B.

4.4 Auxiliary data

Nadir looking high-resolution visual images is available in raw canon format (.CR2), which can be accessed using standard Canon software or other related software programs. The camera is triggered to acquire images along the track at a 5 second interval, and timed tagged with GPS. Each image is 22-28 MB. An example of a jpeg-image from the flight is shown in Figure 10 with size 5184 x 3456 pixels.

Figure 10: Example of vertical image converted to jpeg-format, taken May 3, 2015 at 13:28 UTC.

5 Conclusion

The GNSS FinExp 2015 has collected observations of the instantaneous sea surface heights by ASIRAS radar and ALS to support the SPIR experiment. The data was collected almost coincident with the Skyvan carrying the SPIR instrument flying at the same speed but at different altitude.

The data was found to be of high quality with vertical accuracy of less than 10 cm. In general, the ASIRAS and ALS elevations show good agreement over open water, using the OCOG re-tracker.

6 References

Cullen, R.: CryoVEx Airborne Data Products Description, Issue 2.6.1, ESA, Ref. CS-LI-ESA-GS-0371, 2010

Jain, M., O. B. Andersen, J. Dall, and L. Stenseng (2015). Sea surface height determination in the Arctic using Cryosat-2 SAR data from primary peak empirical retrackers. Advances in Space Research 55, pages 40–50.

1 Appendix – Log file from flight

DOY 123 03-05-2015 EFHF, A-B, B-A, C-D, D-C, A-B, B-A, C-D, F-G, I-J, K-L, EFHF

Operator ALS (LMS Q-240i-80)/OxTS INS: Russell (BAS)
Operator ASIRAS/EGI: Henriette Skourup
Pilot: Mark (BAS)
IATA EFHF Malmi airport, Helsinki

~1250	Start up system
1314	Ready
1315	Taxi
1321	Take off EFHF
1325	ASIRAS calibration
1328	Start record _00
1336	Aligned A-B
1353	Aligned B-A
1409	New record _01
1414	Aligned C-D
1421	Aligned D-C
1426	End of line
1432	Aligned A-B
1445	End of line
1448	Aligned B-A
1504	End of line
1505	New record _02
1511	Aligned C-D
1516	End of line
1520	Aligned F-G
1527	Aligned I-J
1533	Aligned K-L
1536	End of line
1541	New record _03
~1549	Runway overflight EFHF
~1552	Runway overflight EFHF
1558	Calibration, shut down ASIRAS
1600	Landing EFHF

2 Appendix – Overview of acquired ALS file

Date	DOY	ALS raw file	Start (dechr)	Stop (dechr)	Comments
03-05-2015	123	150503_132326_Scanner_1.2dd	15.20848	16.09879	

3 Appendix – Overview of acquired ASIRAS log-files

Date	File name	Start time (UTC)	End time (UTC)	Range window (m)	# Pulses
03-05-2015	A150503_00.log	13:29:57	14:09:43	90.00	5959962
	A150503_01.log	14:09:46	15:05:56	90.00	8419944
	A150503_02.log	15:06:01	15:38:13	90.00	4824968
	A150503_03.log	15:41:20	15:55:05	90.00	2057486

4 Appendix – Overview of processed data files

Date	DOY	Instrument	File name	Size (MB)
2015-05-03	123	GPS	GPS_F_20150503T130454_160605_0001.DBL	0.7
		INS	INS_20140503T130818_160228_0001.DBL	17
		ALS	ALS_20150503T132310_160034.nc	213
		ASIRAS	AS6OA00_ASIWL1B040320150503T132903_20150503T140847_0001.DBL	64
		ASIRAS	AS6OA01_ASIWL1B040320150503T140852_20150503T150500_0001.DBL	90
		ASIRAS	AS6OA02_ASIWL1B040320150503T150507_20150503T153717_0001.DBL	46
		ASIRAS	AS6OA03_ASIWL1B040320150503T154026_20150503T155409_0001.DBL	18

5 Appendix – Processed ASIRAS profiles

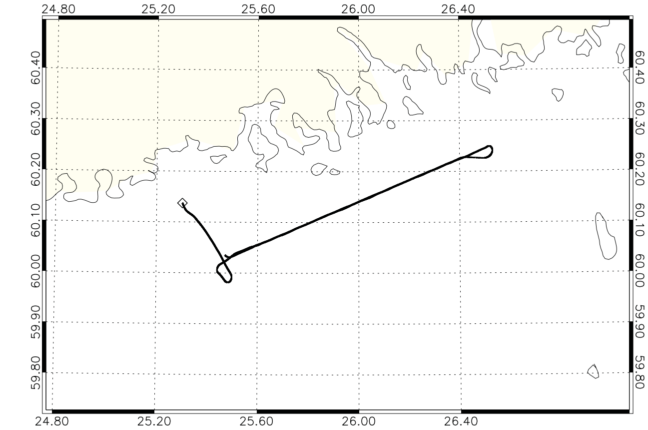
The following plots show all processed ASIRAS profiles with each profile plot consisting of four parts:

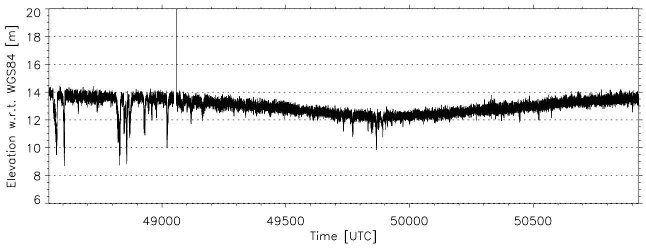
1. Header composed of daily profile number and the date and a sub-header with the filename.
2. Geographical plot of the profile (diamond indicates the start of the profile).
3. Rough indication of the heights as determined with the OCOG re-tracker plotted versus time of day in seconds.
4. Info box with 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 re-tracker is a rough estimate and not a true height.

A150503_00

AS60A00_ASIWL1B040320150503T132903_20150503T140847_0001.DBL

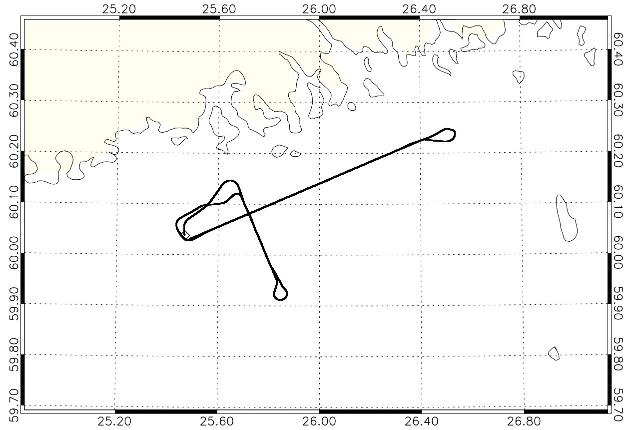


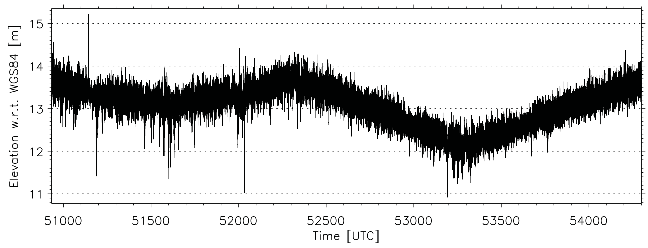


Date	2015-05-03	**Instrument Mode**	Adv. Low Altitude
Start Time	13:29:03 (48543)	**Aircraft**	BAS Twin Otter
Stop Time	14:08:46 (50926)	**Retracker**	OCOG
Distance	156.682 km	**INS Resolution**	50 Hz
Duration	00 h 39 m 43 s	**Processor Version**	0403

A150503_01

AS60A01_ASIWL1B040320150503T140852_20150503T150500_0001.DBL

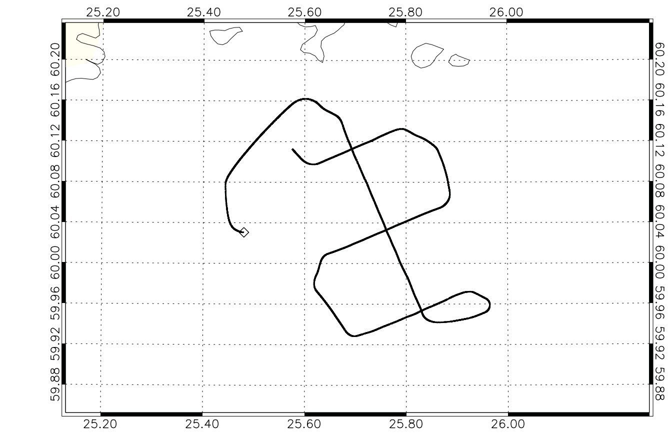


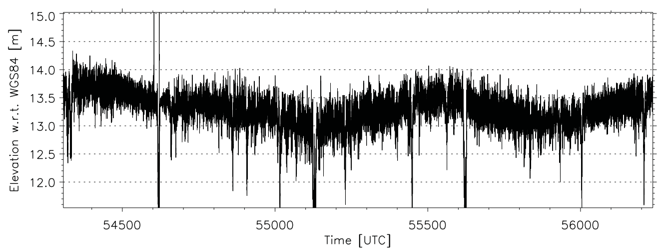


Date	2015-05-03	**Instrument Mode**	Adv. Low Altitude
Start Time	14:08:52 (50932)	**Aircraft**	BAS Twin Otter
Stop Time	15:05:00 (54300)	**Retracker**	OCOG
Distance	221.543 km	**INS Resolution**	50 Hz
Duration	00 h 56 m 08 s	**Processor Version**	0403

A150503_02

AS60A02_ASIWL1B040320150503T150507_20150503T153717_0001.DBL

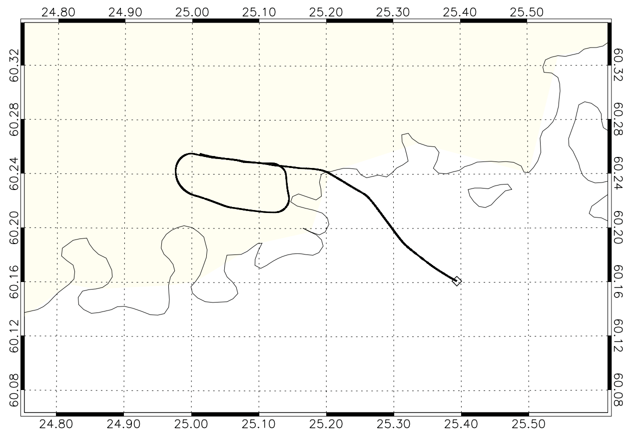


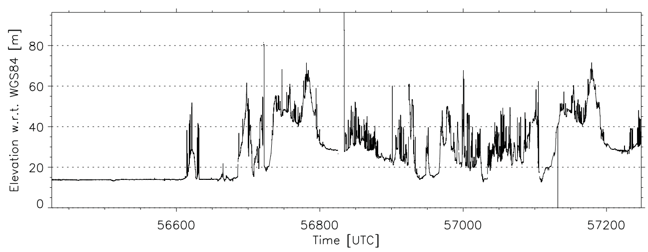


Date	2015-05-03	**Instrument Mode**	Adv. Low Altitude
Start Time	15:05:07 (54307)	**Aircraft**	BAS Twin Otter
Stop Time	15:37:16 (56236)	**Retracker**	OCOG
Distance	121.409 km	**INS Resolution**	50 Hz
Duration	00 h 32 m 10 s	**Processor Version**	0403

A150503_03

AS60A03_ASIWL1B040320150503T154026_20150503T155409_0001.DBL





Date	2015-05-03	**Instrument Mode**	Adv. Low Altitude
Start Time	15:40:26 (56426)	**Aircraft**	BAS Twin Otter
Stop Time	15:54:08 (57248)	**Retracker**	OCOG
Distance	48.474 km	**INS Resolution**	50 Hz
Duration	00 h 13 m 42 s	**Processor Version**	0403

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