ESA CryoVEx/KAREN Antarctica 2017-18

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

S. M. Hvidegaard, R. Forsberg, H. Skourup, M. L. Kristensen, A. V. Olesen, A. F. Olesen, A. Coccia, K. Macedo, V. Helm, R. S. Ladkin, R. Tilling, A. E. Hogg, Adriano Lemos and A. Shepherd

DTU Space
National Space Institute
Technical University of Denmark

Technical Report
October 2020

EUROPEAN SPACE AGENCY CONTRACT REPORT

ESA Contract No. 4000124829/18/NL/AI

ESA CryoVEx/KAREN Antarctica 2017-18

Final Report

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

Authors:

S. M. Hvidegaard¹, R. Forsberg¹, A. V. Olesen^{1*}, H. Skourup¹, M. L. Kristensen¹, A. F. Olesen¹, A. Coccia², K. Macedo², V. Helm³, R. Tilling^{4,6}, A. E. Hogg⁵, Adriano Lemos⁵ and A. Shepherd⁵

¹ National Space Institute, DTU Space, Denmark

² MetaSensing BV, The Netherlands

³ Alfred Wegener Institute for Polar and Marine Research, Germany

⁴ University College London, UK

⁵ University of Leeds, UK

⁶ University of Maryland/NASA GSFC, USA

**Now at Westgaard GeoSolutions*

ESA technical officer: Tânia Casal

DTU Space
National Space Institute
Danish Technical University

Technical Report, 2020
ISBN 978-87-91694-50-9

Front cover photo: Collecting data over the southern part of the Antarctic Peninsula

ESA contract report

CryoVEx/KAREN Antarctica 2017-18 airborne field campaign

Version: 2.0

ESA STUDY CONTRACT REPORT			
ESA CONTRACT NO 4000124829/18/NL/AI	SUBJECT Technical Support for Antarctica CryoVEx/KAREN 2017/18		CONTRACTOR National Space Institute (DTU Space)
ESA CR No	STAR CODE	No of volumes 1 This is Volume No 1	CONTRACTORS REFERENCE CryoVEx/KAREN Ant
<p>ABSTRACT</p> <p>This report summarizes processing of the collected data from the ESA CryoVEx/Karen 2017-18 campaign in Antarctica 2017-18. The airborne and in-situ campaign in Antarctica acquired extensive data sets of scanning lidar, Ku- and Ka-band nadir-looking radar, and auxiliary imagery for validation of the ESA CryoSat-2 satellite (Ku-band radar altimetry) and the French-Indian AltiKa mission (Ka-band radar altimetry).</p> <p>The primary goal of the campaign was to acquire data for studying the radar penetration of Ku- and Ka-band radar in snow and firn over the sea ice and ice sheet, and was supported by a field team from University of Leeds taking shallow cores on the southern part of the Antarctic Peninsula. Another field team from UCL, UK, collected sea ice thickness and snow depth data on Antarctic Sea Ice in the Weddel Sea, in connection with the resupply cruise of the British Antarctic Survey R/V Shackleton, providing another validation opportunity for the validation of the airborne and satellite data.</p> <p>The CryoVEx-2017/18 field campaign was successful, collected more than 10 TB of raw data (as outlined in the Data Acquisition Report, and demonstrated – thanks to excellent logistics cooperation with the British Antarctic Survey – that relatively large satellite validation campaigns can be carried out in remote locations of Antarctica at a comparative costs level to similar Arctic activities, when using logistics “windows of opportunity” for national logistics support.</p> <p>The final processed data outlined in this final report will be made available for general access at the ESA campaigns web site.</p>			
<p>The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organization that prepared it.</p>			
<p>Names of authors: S. M. Hvidegaard, R. Forsberg, H. Skourup, A. V. Olesen, M. L. Kristensen, A. F. Olesen, A. Coccia, K. Macedo, V. Helm, R. Tilling, A. E. Hogg, and A. Shepherd</p>			
<p>NAME OF ESA STUDY MANAGER Tânia Casal Mission Science Division Campaigns Section - ESTEC</p>		<p>ESA BUDGET HEADING</p>	

DOCUMENT CHANGE LOG

Version	Date	Modified pages	Modifications
1.0	12/12-2019	all	Document created, H. Skourup
1.0	June 2020	all	Draft delivered to ESA, S. M. Hvidegaard
1.1	Sept. 2020	1-28, 47-57, App 22	Updates after ESA comments
2.0	Oct. 2020	Appendix added	Final version after approval

Contents

1	Introduction.....	8
2	Summary of operation	10
2.1	Day to day.....	13
3	Hardware installation	15
4	Overview of acquired data	18
5	Processing.....	21
5.1	GPS data processing	21
5.2	Inertial Navigation System	22
5.3	Airborne Laser Scanner (ALS)	23
5.3.1	Calibration	23
5.3.2	Laser scanner outlier detection and removal.....	24
5.3.3	Cross-over Statistics	24
5.3.4	Final processed data.....	25
5.4	ASIRAS	27
5.4.1	Processing.....	27
5.4.2	Final processed data.....	27
5.5	KAREN.....	28
5.5.1	Processing.....	28
5.5.2	Final packed data.....	29
5.6	Calibration and absolute heights of ASIRAS and KAREN	32
5.7	Horizontal alignment between ASIRAS and KAREN	36
5.8	Camera	39
6	Calibration and Validation sites.....	40
6.1	Sea Ice.....	41
6.1.1	Sea Ice in situ data from RRS Ernest Shackleton	43
6.1.2	First results of dual-frequency sea ice observations from KAREN and ASIRAS.....	46
6.2	Land ice.....	50
6.2.1	In situ data from flights around SkyBlu	50

6.2.2	First results	53
	Conclusion	55
7	References	56
8	APPENDIX Operator logs	57
9	APPENDIX Coordinates of GPS base stations	71
10	APPENDIX Overview of acquired ALS data	72
11	APPENDIX Overview of acquired ASIRAS data	75
13	APPENDIX Overview of acquired data from Ka-band radar	77
14	APPENDIX File name convention.....	80
15	APPENDIX Processed GPS data in ESA format.....	81
16	APPENDIX Processed INS data in ESA format.....	82
17	APPENDIX Processed ALS data	83
18	APPENDIX Time-tagged and geo-located images.....	85
19	APPENDIX Processed KAREN data	86
20	APPENDIX Processed ASIRAS data.....	89
21	APPENDIX Final ASIRAS profiles	92
22	APPENDIX KAREN processing report.....	

1 Introduction

The ESA CryoVEx-Karen airborne satellite validation campaign in Antarctica was successfully carried out in the period Dec 20, 2017 to Jan 16, 2018, taking advantage of several logistics opportunities for support from the British Antarctic Survey (availability of aircraft and pilot support and also, Rothera Station support for the team, and support for in-situ measurements both over land ice and sea ice). The field campaign was set up at relatively short notice, and set up along the same principles and instrumentation as in earlier arctic campaigns (scanning lidar for measurement of precise snow and ice heights, Ku-band (13 GHz) radar ASIRAS as a proxy for CryoSat-2 measurements, and a recent developed Metasensing Ka-band radar altimeter (38 GHz), providing an airborne equivalent of the AltiKa radar (36 GHz).

The campaign flight program was set up to attempt to fly several near-realtime underflights of both the CryoSat-2 and the AltiKa radar altimetry missions, both over sea ice in the Weddel Sea, over the Ronne and George VI ice shelves, as well as further inland over Antarctic ice sheet regions. This was a challenging planning effort due to the day-to-day changes in orbit ground tracks, which meant that underflight opportunities had to be continuously re-evaluated, to allow for changing weather and logistics constraints. A total of ca. 60 flight hours was flown, sampling a large variety of cryosphere regions from Antarctic sea ice, ice shelves, nunatak ice cap zones on the Antarctic Peninsula, and deep interior high-elevation ice sheet regions around the Ellesworth Mountains, the highest mountains in Antarctica.

Figure 1: Overview of the flight tracks from the CryoVEx/KAREN Antarctic 2017-18 airborne campaign.

The new data from CryoVEx 2017/18 will allow an enhanced quantification of radar signal penetration into the Antarctic cryosphere, and thus potentially improved measurement of ongoing ice sheet, ice shelf and sea ice changes, as well as provide a demonstration experiment for a future multi-frequency radar altimetry mission, such as the Copernicus High Priority Candidate Mission CRISTAL. The airborne flight tracks are shown in Figure 1.

The airborne measurement program was complemented by an ice cap /ice shelf University of Leeds/BAS field team, carrying out in-situ measurements on ice sheet and ice shelf regions in the southern Antarctic Peninsula region in the days Jan 12-16, 2018, using a 2nd BAS Twin-Otter for logistics support. The in-situ data acquired included snow properties and shallow ice core measurements at 8 sites, coordinated with airborne overflights, and coincident with CryoSat-2 orbit tracks. The location of the in-situ sites is shown in Figure 2, along with the near-coincidental CryoSat tracks.

Another UK team, led by Rachel Tilling (University College London), was doing sea ice measurements from the BAS icebreaker R/V “Ernest Shackleton”. Ice thickness, snow depth, and broadband radar measurements were carried out on an opportunity basis in the Weddell Sea, as part of the BAS resupply of Halley Station and fuel depots on the Ronne-Filchner ice Shelf. Coordinated airborne overflights were done at two in-situ data locations (near the ice shelf front at Three Ronne Depot (TRD), and over a major ice-floe about 200 km to the NE of TRD, marked with “ES” in Figure 1). The sea ice overflights consisted of a local pattern along predetermined in-situ data lines. Logistics allowed a visit of the airborne survey crew to meet visit the R/V Shackleton at the TRD, facilitating the flight/in-situ coordination.

This report is an ESA CryoVEx contract report describing the experiments and it summarizes the airborne and in situ field operations, instrument description and data processing together with first results.

The primary objectives achieved during the campaign were:

- To fly dual frequency (Ka/Ku-band) radar altimeters together with laser to study penetration depths and key properties of Antarctic conditions in support of future satellite missions
- Coordinated land sea ice underflights of CryoSat-2 and SARAL/AltiKa in different locations
- Coincident flights with in situ observations on sites on both land and sea coordinated with ground team

Figure 2. Left: Location of the in-situ ice cap (T2, T4, T6, T8) and ice shelf (T1, T3, T5, T7) UL shallow drilling locations, overlaid by airborne tracks(white); topography in colours. Right: Offloading drilling equipment at the Stange Ice Shelf in-situ site (T3).

Figure 3. Left: R/V Ernest Shackleton at Three Ronne Depot (Alex Coccia, Metasensing, in front). Right: R/W Shackleton moored at large ice floe in the central Weddell Sea (photos: Dave Landy, BAS).

2 Summary of operation

The CryoVEx 2017-18 campaign was started ahead of the first field crew arriving at Rothera on Dec 20, by Russell Ladkin, BAS aircraft technician. The airborne lidar and radar equipment was installed in the BAS Twin-Otter aircraft VP-FAZ, taking advantage of existing BAS hardware (VP-FAZ has been used regularly for other science flights, including first BAS/DTU cooperative flights with lidar as early as in 2010). An additional Twin-Otter aircraft, VP-FBL, was used to support the deployment of the UL/BAS field team in the southern Peninsula region, operating out of the BAS SkyBlu summer camp, a high-altitude blue ice runway, where wheel landings with the larger BAS Dash-7 support aircraft are possible.

The main timeline of operations is shown below in Table 1 along with a detailed “day-to-day”-report in Section 2.1. The operations, given the logistics and remote operations under challenging Antarctic

conditions, were actually quite close to the original time plan [RD1], although the actual layout of airborne flight tracks is quite different. A detailed overview of day-by-day flights with take-off and landing times, as well as status of the collected data, is given in Appendix 9.

The flight altitude during the CryoVEx survey flights was typically 300 m agl, limited by the range of the laser scanner, and with a nominal ground speed is 135 knots. The aircraft was equipped with an extra ferry tank permitting longer flights, and an autopilot for better navigation accuracy (in good conditions the across-track accuracy is down to a few meters using a DTU custom-made navigation system connected to geodetic GPS receivers). Calibration flights of the instruments over buildings and runways were performed at Rothera (with GPS survey ground truth), as well as over the Sky Blue blue ice airstrip (snowmobile GPS survey). For a more detailed description of the lidar and radar calibration see Section 5.3 and 5.4. Details of the CryoVEx flights are shown in Table 2.

The airborne CryoVEx 2017-18 science team consisted of Arne V. Olesen and Rene Forsberg (DTU Space) and Alex Coccia (MetaSensing), with ESA technical officer Tânia Casal participating on behalf of ESA. Russell Ladkin (British Antarctic Survey) assisted with the instrument installation, and the skills of BAS pilot David Landy was instrumental for the success of the campaign.

The land ice ground team consisted of Andy Shepard, Adrianos Lemos, and Anna Hogg (University of Leeds). The in-situ sea ice team Rachel Tilling (University of Leeds) and ph.d. student Isabel Nias (University of Bristol). The land ice ground team was part of the CryoVEx team, whereas the sea ice ground team was a British funded project, using the logistical support from R/V Shackleton resupply cruise in the Weddell Sea.

Figure 4. Top: BAS main base Rothera, one of only 3 hard-rock runways in Antarctica. Hangar at lower left.

Table 1. Main time line of Antarctic operations

Dec 20-26, 2017	Arrival of DTU/Metasensing team from Punta Arenas, Chile. Installation and instrument tests at Rothera
Dec 28-29	Transit to Halley Station, East Antarctica, via Three Ronne Depot
Dec 30-31	Measurement flights from Halley over sea ice and land ice
Jan 2-7, 2018	Return of aircraft to Rothera for maintenance, 2nd sea ice flight over RV Shackleton
Jan 6-10	Crew Exchange, Alex Coccia (Metasensing) return, Rene Forsberg (DTU Space), Adrianos Lemos (U.ni. of Leeds), and Tania Casal (ESA) arrive for 2nd phase of CryoVEx/Karen, focusing on land/ice shelf ice
Jan 11-14	Operations from SkyBlu, with U Leeds field team (Andy Shepherd and Anna Hogg, with assistance from Tom Lawfield (field guide) and Alex Grievson (electronics engineer)) Sea ice flight over Weddell Sea on return leg to Rothera
Jan 15-16	Local calibration flight around Rothera (partly aborted due to weather conditions); uninstalling aircraft instruments and preparation of cargo and shipping
Jan 20	CryoVex-2017/18 return flight to Punta Arenas

Figure 5. Left: Aircraft at SkyBlu runway; right: SkyBlu field camp

Table 2: Overview of CryoVEx/KAREN Antarctic 2017-18 flights. Initials of survey operators are Arne V. Olesen (AVO), Rene Forsberg (RF) and Alex Coccia (AC).

Date	DOY	Flight	Track	Take off UTC	Landing UTC	Airborne	Airborne accumulated [dd:hh:mm]	Survey operator
26/12 2017	360		Test flight ROT	15.14	16.18	01.04	00.01.04	AVO/AC
27/12 2017	361		Test flight ROT	12.58	13.40	00.42	00.01.46	AVO/AC
28/12 2017	362		ROT-FBL	12.43	14.38	01.55	00.03.41	AVO/AC
			FBL - TRD	15.32	19.05	03.33	00.07.14	
29/12 2017	363		TRD-SeaIce-HAL	12.38	17.18	04.40	00.06.26	AVO/AC
30/12 2017	364		HAL-Sea Ice-HAL	09.28	14.23	04.55	00.11.21	AVO/AC
31/12 2017	365		HAL-HAL	10.20	14.54	04.34	00.15.55	AVO/AC
02/01 2018	2		HAL-Shackleton-BSD	09.53	15.00	05.07	00.21.02	AVO/AC
03/01 2018	3		BSD-SBR	19.19	00.37	05.18	01.02.20	AVO/AC
05/01 2018	5		SBR-ROT	11.33	15.30	03.57	01.06.17	AVO/AC

06/01 2018	6		ROT-LarsenTriangle-ROT	14.05	18.51	04.46	01.11.03	AVO/AC
09/01 2018	9		ROT-SBR	17.47	21.27	03.40	01.14.43	AVO/RF
10/01 2018	10a		SBR-BMS	08.38	12.12	03.34	01.18.17	AVO/RF
10/01 2018	10b		BMS-SBR	14.01	17.50	03.49		AVO/RF
13/01 2018	13		SBR-SeaIce-SBR	12.39	15.52	03.13	01.21.30	AVO/RF
14/01 2018	14a		SBR-SBR	11.50	13.10	01.20	00.01.20	AVO/RF
14/01 2018	14b		SBR-CSseaice-ROT	22.15	03.43	05.28	02.02.58	AVO/RF
15/01 2018	15			18.09	19.54	01.45	02.04.43	AVO/RF
Total							60h 18m	

2.1 Day to day

The airborne part of CryoVEx/KAREN Antarctica 2017-18 campaign progressed as follows:

- Dec 20-27 Installation and instrument tests at Rothera, by Arne Olesen (DTU Space) and Alex Coccia (Metasensing) in cooperation with BAS air unit mechanics.
- Dec 28-29 Transit to Halley Station, East Antarctica, via Three Ronne Depot for 1st phase of CryoVEx/KaREN focussing on sea ice. 1st coordinated sea ice flight with R/V Shackleton on sea ice off TRD.
- Dec 30-31 Measurement flights from Halley over sea ice and land ice, with several underflights of CryoSat-2 and AltiKa.
- Jan 2-5 Return of aircraft to Rothera for scheduled maintenance, with 2nd coordinated sea flight over R/V Shackleton, and survey flights across the Ronne Ice Shelf.
- Jan 5-7 Alex Coccia (Metasensing) returns to South America. Rene Forsberg (DTU Space), Adrianos Lemos (Uni. Of Leeds), and Tania Casal (ESA) arrive for 2nd phase of CryoVEx/Karen, focussing on land ice/ice shelves and in-situ programme.
- Jan 9-10 Second phase of operations, focussing on land ice and ice shelf regions in Peninsula and deep interior regions.
- Jan 11-14 Operations from BAS summer base SkyBlu, with U Leeds field team (Andy Shepherd and Anna Hogg, with assistance from Tom Lawfield (field guide) and Alex Grievson (electronics engineer) from BAS) collecting in-situ data at 8 sites, coordinated with aircraft overflights. Aircraft return to Rothera late evening Jan 14 along CryoSat line in Weddell Sea.
- Jan 15 Last calibration flight over Rothera; last in-situ team data collection on Ronne Ice Shelf.
- Jan 16 Field and airborne teams meeting at Rothera, uninstalling aircraft survey equipment, and preparation of cargo and shipping, including ice cores shipped to Cambridge for further analysis
- Jan 20 Return flight northbound.

3 Hardware installation

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

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

- MetaSensing Ka-band radar altimeter KAREN
- ESA Ku-band interferometric radar ASIRAS
- BAS Airborne Laser Scanner (ALS) of the type Riegl LMS Q-240i-80
- 2 geodetic dual-frequency GPS receivers of type Javad delta (AIR2/4)
- An Inertial navigation system (INS) of the type Honeywell H-764G
- Supplementary iMAR RQH-0001 inertial survey system (DTU Space). This IMU was carried as a back-up unit, as well as an experimental gravimeter.
- An Inertial navigation system (INS) of the type OxTS xNav 550 (backup)
- A NovaTel integrated GPS-INS system of type SPAN-CPT to support KAREN (backup)
- Side-looking and nadir cameras (Canon and web cam)

The ALS setup is similar to the setup in the same aircraft during EU ICE-ARC/ESA FinExp campaign in 2015 (Hvidegaard et al., 2017). All instruments were mounted in the camera hatch located below the floor in the cabin (Figure 7-10), except for the Honeywell INS and iMAR unit, which were mounted on the floor below the operator seat in the cabin (Figure 7).

Camera Hatch Antenna (F) was connected to AIR4 Javad Delta Receiver, and camera Hatch Antenna (G) was connected to AIR2 Javad Delta Receiver.

The instruments were mounted in the aircraft and tested at at Rothera. The lever arms from GPS antenna to KAREN and ALS reference points are given in Table 4, and the hardware installation can be seen in Figure 8-10.

Table 3: The dx, dy and dz offsets for the lever arm from the GPS antenna to the origin of the laser scanner, the KAREN and ASIRAS reference points.

To laser scanner	dx (m)	dy (m)	dz (m)
from Camera Bay GPS antenna (F)	+ 0.27	+ 0.05	+ 1.55
from Camera Bay GPS antenna (G)	+0.82	-0.31	+1.58
To KAREN reference point	dx (m)	dy (m)	dz (m)
From Camera Bay GPS antenna (F)	+0.16	+0.12	+1.68
from Camera Bay GPS antenna (G)	+0.71	-0.24	+1.71
To ASIRAS reference point	dx (m)	dy (m)	dz (m)
From Camera Bay GPS antenna (F)	-0.82	+0.05	+1.92
from Camera Bay GPS antenna (G)	-0.27	-0.31	+1.95

Figure 7: Overview of instrument setup in the VP-FAZ Twin Otter aircraft

Figure 8: Instrument installation in the camera bay below the floor in the Twin Otter cabin; ALS (left), Oxts INS (middle right). Note ALS and Oxts INS axis are mounted along aircraft centre line. Installation: Forward to left. Aircraft right is at the top.

Figure 9: Bottom view of the BAS Twin-Otter VP-FAZ showing KAREN, ALS together with ASIRAS antenna.

Figure 10. Rack setup in BAS Twin Otter VP-FAZ. ASIRAS operator screen (left), and the ASIRAS antenna mounted under the VP-FAZ.

4 Overview of acquired data

Data from the various instruments were acquired where feasible, considering the limited range of the ALS system and the weather. An overview of all acquired data is listed in Table 4.

The sampling frequency of the KAREN sensor was set to 25 MHz corresponding to one sampling each ~30cm on the ground. The high sampling frequency results in a large amount of 360 GB of raw data per hour, plus a few MB of navigation data (dedicated GPS/IMU module). Acquisitions have been manually started and stopped by the operator according to the area which was flown; data sets of typically 10-30 minutes duration have been logged. At the end of the campaign the raw data amount is ~10 TB. During the flight and at the end of each acquisition day a quick data look was performed on randomly selected dataset to assess the quality and eventually adjusting the Pulse Repetition Frequency (PRF) according to the flight altitude. Data was primarily gathered at low altitude consistent with the range of the ALS but also High Altitude Mode (HAM) was tested on selected flight lines.

ASIRAS data was mainly acquired in Low Altitude Mode (LAM) with low along-track resolution (LAMa) but also a few selected lines were observed in HAM after initial malfunction of PC2 was repaired. One of the embedded ASIRAS computers ("PC2") was non-functional upon arrival in Antarctica, which

ruled out any data collection in HAM (SarIn) mode; it was only repaired partially after consultations with RST mid-campaign, but PC2 continued to be unstable until the last flights. LAMa 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 about 1 TB raw ASIRAS data was collected during the campaign. The data were stored on hard discs as ASIRAS level 0 raw data in the modified compressed format (Cullen, 2010).

The lidar, GPS and Honeywell IMU instrumentation worked flawlessly during the campaign, while the radars and nadir looking cameras had several problems. For the cameras, data were only collected where it made sense (e.g., over sea ice and mountains, but not over featureless ice sheet and shelf surfaces).

The data volume obtained by the ALS is about 250-300 MB per hour, which is a relatively small amount, when compared to the ASIRAS data volume. During the campaign a total of 32.8? GB ALS data was acquired.

The airborne GPS units logged data internally in the receivers during flight, which were downloaded upon landing on laptop PCs. The GPS reference stations listed in Table 4 are described in further detail in Section 5.1. One inverter failure on January 5th caused a gap in GPS data collection and missing EGI data for the rest of the flight – backup INS could be used though.

Overall, more than 10 TB data were collected. Nearly all satellite underflights had all three airborne data types (lidar, Ku- and Ka-band radar) collected, as also indicated in Appendix 10 and Figure 1.

Table 4. Data acquisition overview

Date	DOY	AIR2	AIR4	EGI H-764G	INS OxTS	iMAR ³	ALS	ASIRAS	KAREN	VER CAM	SLANT CAM	GPS REF	Log	Remarks
26-12-2017	360	X	X	X	X	-	X	-	X	-	-	-		PC2 failure
27-12-2017	361	X	X	X	X	-	X	X	X	-	-	X	X	RWY cal
28-12-2017	362a	X	X	X	X	-	X	X	X	-	-	X	X	
28-12-2017	362b	X	X	X ¹	X	-	X	X	X	-	-			
29-12-2017	363	X	X	X	X	-	X	X	X	-	-	X	X	
30-12-2017	364	X	X	X	X	-	X	X	X	-	-	-	X	
31-12-2017	365	X	X	X	X	-	X	X	X	-	-	-	X	
02-01-2018	002	X	X	X	X	-	X	X	X	-	X ⁴	-	X	
03-01-2018	003	X	X	X	X	-	X	X	X	-	-	X	X	
05-01-2018	005	X	X	X ²	X	-	X	X ²	X ²	-	-	X	X	Inverter failure
06-01-2018	006	X	X	X	X	-	X	X	X	-	X ⁴	X	X	
09-01-2018	009	X	X	X	X	-	X	X	-	X	-	-	X	
10-01-2018	010a	X	X	X	X	-	X	X	- ³	-	-	-	X	KAREN failure
10-01-2018	010b	X	X	X	X	-	X	X	- ³	-	-	-	X	KAREN failure
13-01-2018	013	X	X	X	X	-	X	X	X	X	X ⁴	-	X	
14-01-2018	014a	X	X	X	X	-	X	X	X	-	X ⁴	-	X	
14-01-2018	014b	X	X	X	X	-	X	X	X	X	X ⁴	-	X	
15-01-2018	015	X	X	X	X	-	X	X	X	X	-	X	X	RWY cal

- 1) Small gaps in data, few seconds
- 2) Gap in data coverage due to inverter failure
- 3) No data logged, instrument failure
- 4) Only over sea ice and reasonable visibility

5 Processing

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

The final campaign data files can be requested through the ESA portal:

The following sub-sections provides more details regarding the data processing for each of the essential instruments.

5.1 GPS data processing

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

A Javad Maxor Receiver (REF) with internal antenna and logging rate 1 Hz were used as temporary base station. The base station was mounted on DTU Space small tripods (vertical height 12 cm). However, the reference points were generally not marked, and thus the reference stations were not placed at the exact same position for the different flights, and a reference point must be calculated for each flight. The positions of the temporary base stations are determined using the online GPS processing services AUSPOS (<http://www.ga.gov.au/earth-monitoring/geodesy/auspos-online-gps-processing-service.html>) offered by Geoscience Australia. The service calculates the position of the CryoVEx/KAREN Antarctica 2017-18 airborne field campaign

reference stations in the ITRF 2014 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 polar regions with long distances to the closest permanent stations. The coordinates of all the reference stations used during CryoVEx Antarctica 2017/18 are found in Appendix 10.

The GPS processing was performed with Waypoint GrafNav (version 8.40) by use of precise IGS orbit and clock files and correction for ionospheric and tropospheric errors. For each flight several solutions are made using different combinations of GPS reference stations and aircraft receivers. The best solution for each flight is selected according to Table 5 and used in the further processing.

5.2 Inertial Navigation System

The position and attitude information (pitch, roll and heading) observed with the INS instrument are reduced from 50 Hz to 10 Hz and then 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.

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

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 4. As seen, most solutions are based on the primary Honeywell (H-764G) INS unit. Attitude information from the backup OxTS was used on a subsection of the flight January 5th, due to an inverter failure.

A prior version the OxTS Nav 550, the Inertial+2, has degraded accuracy during acceleration, which includes turns and rapid changes of altitude (Skourup et al., 2012). This could be the case also for the OxTS Nav 550, however, as this unit was only used to patch in very short straight sub-sections of the flight on January 5th, it is not expected to decrease the accuracy of this particular flight.

The best solutions of both GPS and INS data as listed in Table 5, is packed as binary files in the ESA file format also used for similar campaigns, see Cullen (2010). An overview of the final GPS and INS files is listed in Appendix 16 with file name convention according to Appendix 15.

Table 5 List of best combination of GPS and INS data

Date	DOY	GPS rover	Reference GPS	GPS processing	INS
26-12 2017	360	AIR4	ROT	DIF	H-764G
27-12 2017	361	AIR4	ROT	DIF	H-764G
28-12 2017	362	AIR4	-	PPP	H-764G
29-12 2017	363	AIR4	-	PPP	H-764G
30-12 2017	364	AIR2	HAL	DIF	H-764G
31-12 2017	365	AIR4	HAL	DIF	H-764G
02-01 2018	002	AIR4	-	PPP	H-764G
03-01 2018	003	AIR4	-	PPP	H-764G
05-01 2018	005	AIR4	-	PPP	H-764G/OxTS
06-01 2018	006	AIR2	REF	DIF	H-764G
09-01 2018	009	AIR4		PPP	H764G
10-01 2018	010	AIR4	-	PPP	H-764G
10-01 2018	010	AIR4	-	PPP	H-764G
13-01 2018	013	AIR4	REF	DIF	H-764G
14-01 2018	014	AIR4	-	PPP	H-764G
14-01 2018	014	AIR4	-	PPP	H-764G
15-01 2018	015	AIR4	REF	DIF	H-764G

5.3 Airborne Laser Scanner (ALS)

The LMS Q-240i-80 Laser scanner operates with wavelength 904 nm and is therefore expected to reflect on the air-snow (or air-water) interface for cloud free conditions on the land and sea ice targets of this campaign. The spatial resolution was chosen to give a regular coverage of the surface with approximately 1 point/m² corresponding to 40 scan lines per second with 251 laser shots per line. These settings result in a swath width of ~400 m at 300 m flight height a.g.l.

The raw range observations are combined with position and attitude information from the GPS/INS solutions to provide 3D surface information. The vertical accuracy is in the order of 10 cm depending primarily on uncertainties in the kinematic GPS-solutions. The raw logged files, named by start times, are listed in Appendix 12.

5.3.1 Calibration

Calibration of ALS misalignment angles between ALS and INS can be estimated from successive overflights from different directions of the same building, where the position of the corners is known with high precision from GPS measurements. For this purpose, building overflights were performed at Rothera on December 26 and 27 (DOY 360, 361) and on January 15 (DOY 015).

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 Section 5.3.3 and also in Appendix 11. An example of ALS elevations from overflight of the calibration building and runway at Rothera is given in Figure 11.

Figure 11. ALS elevations (w.r.t. WGS-84) of the calibration building and runway Rothera.

5.3.2 Laser scanner outlier detection and removal

The 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 a selected range (typically 50m) to the aircraft, by using input from processed GPS-heights and/or removal of a selected range window about the vertical elevation.

5.3.3 Cross-over Statistics

As a part of the processing routine, crossover statistics are derived for repeated overflight. The quality of these crossover statistics varies depending on surface type, incidence angle and level of

processing. In general, statistics over sea ice is poor due to the drift of sea ice between inter-sections and only land ice examples are presented. The statistics based on raw scanner data after outlier editing are summarized in Table 6, and an example of cross-over given in Figure 12. The mean elevation differences in the cross-over points are typically less than 10 cm, and mainly represent errors in the GPS solutions. The standard deviation of the cross-over differences is 6-10 cm over flat surfaces. These values are within the expected ranges and reflect data of high quality.

Table 6. Cross-over statistics. Highlighted cross-overs are example provided in Figure 14.

Date	DOY	X-over	Mean (m)	Std. Dev. (m)	Min. (m)	Max (m)	Notes
20171231		X0	0.01	0.08	-0.39	0.37	Ant. Ice sheet
		X1	0.00	0.09	-0.69	0.46	Ant. Ice sheet
		X2	0.04	0.08	-0.36	0.45	Ant. Ice sheet
20180103		X0	-0.03	0.07	-0.33	0.29	Ant. Ice sheet
20180110		X0	0.11	0.06	-0.14	0.38	Ant. Ice sheet
		X1	0.07	0.06	-0.47	0.36	Ant. Ice sheet

5.3.4 Final processed data

Processed ALS data comes as geo-located point clouds, in lines of width 300-400m 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 ALS data files are packed in netcdf4 format. An overview of the processed data is given in Figure 13 together with Appendix 18. Note that broken lines are due to local cloud cover or flight elevations beyond the range of the ALS instrument.

Figure 12. ALS cross-over elevation differences from flight December 31, 2018.

Figure 13. Mission overview of the processed ALS data. All recorded heights are given as geo-located point-clouds with respect to the WGS-84 reference ellipsoid.

5.4 ASIRAS

The ASIRAS radar operates at 13.5 GHz with footprint size 10 m across-track and 3 m along-track at a standard flight height of 300 m. The range resolution for ASIRAS is 0.1098m. ASIRAS specifications are provided in Table 7. An overview of the acquired ASIRAS log-files together with start/stop times, range window and number of pulses are listed in Appendix 12.

5.4.1 Processing

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

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

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

5.4.2 Final processed data

The final processed ASIRAS level-1b data is delivered in the special ESA format as defined in Cullen (2010). A list of final level-1b files is available in Appendix 21 and a summary of the processing is given in Appendix 22 together with plots of each profile.

Note that preliminary analysis of files from HAM tests show issues and need further examination.

Table 7. Specifications of ASIRAS and KAREN at 300m flight altitude above the surface

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

5.5 KAREN

The KAREN airborne instrument is an interferometric frequency modulated continuous wave (FMCW) SAR altimeter working at the Ka-band with central frequency of 34.525 GHz. The sensor operates with FMCW radar modulation in interferometric mode (SARIn), with one transmitting antenna and two receiving antennas. These are patch antennas, as opposed to the CryoVEx/KAREN 2016 fall campaign where horn antennas were used. Radiation characteristics of the patch antennas include a gain of 22 dBi and a 3dB aperture of $15^\circ \times 4.6^\circ$ (along track and cross track). The processed multi-looked data corresponds to an along- and across-track footprint size of 5 m (100 looks) and 12 m, respectively. The vertical resolution is 0.1650 m. KAREN specifics are provided in Table 7 together with similar for ASIRAS. An overview of the acquired data is provided in Table 1 and Appendix 14. The name of each file represents the date and starting time of the acquisition. For each acquisition the file size and some additional notes are given, such as duration of acquisition, altitude of the aircraft during the acquisition and area of interest.

5.5.1 Processing

The final KAREN version “levc” processing chain is similar to ASIRAS in High Altitude Mode (HAM) and introduces several steps going from the raw data format (level-0) to the final delivered data format (level 1B), including range compression (FFT and Hamming filtering), zero-Doppler filtering, ground-back projection (GBP), and multi-looking. For a more detailed description see the “KAREN altimeter - Processing chain and file format” documentation (MS-DTU-KAR-03-PFF-030), attached in Appendix 22. During the processing chain each KAREN data point is geo-located using input from best solutions of GPS and INS data provided by DTU units according to Table 4, and corrected for lever-arms between GPS antenna and KAREN reference points provided in Table 3.

Several plots generated in-flight during acquisitions for quick-data analysis purposes are shown in Figure 14. A detailed example of a Range Doppler map is shown in Figure 15 and an example of a delivered KAREN waveforms plotted in terms of range-delay versus time is provided in Figure 16 with the return energy colour-coded and expressed in dB. For convenience, the time axis is shown in time since the beginning of acquisition.

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

5.5.2 Final packed data

The final data is packed in netcdf format and includes position and attitude of each measurement, full waveform information, as well as phase and coherence from the use of dual antennas in the interferometric mode. The retracking is left to the user, as the choice of retracker depends on user requirements. An overview of the final data is provided in Appendix 20.

Figure 14. Plots generated during flight for quick control (from an earlier campaign).

Figure 15. Example of Range-Doppler map.

Figure 16. Example of KAREN Range-delay versus time dataset provided in the delivered NetCDF files.
The colormap is expressed in dB.

5.6 Calibration and absolute heights of ASIRAS and KAREN

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

The runway overflights performed during CryoVEx/KAREN Antarctica 2017/18 campaign is listed below:

- 26-12-2017 DOY 360 Rothera
- 27-12-2017 DOY 361 Rothera
- 09-01-2018 DOY 009 Rothera
- 14-01-2018 DOY 014 SkyBlu
- 15-01-2018 DOY 015 Rothera

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

In the following we compare ALS surface elevations with OCOG and TRMFA 50% retracked elevations from ASIRAS and KAREN. All radar elevations with roll angles below/above -1.5/1.5, has been discarded due to waveform blurring. For each ASIRAS and KAREN elevation we use a search radius of 3m and 5m, for ASIRAS and KAREN, respectively, corresponding to 4-5 ALS elevations to account for the extent of the footprint size of the radar systems. The ALS elevations within the search radii are averaged and subtracted from the radar elevation. A total mean is given for each runway overflight representing the off-set provided in Tables 8 and 9. In addition, standard deviation and percentage of accepted points due to the limits on roll are also provided.

Runway overflights in Rothera (ROT) and SkyBlue (SKY) have mean offsets between ALS-KAREN elevations of -0.03 m (-0.02 m) using OCOG (TRMFA 50%) retrackers respectively and between ALS-ASIRAS elevations of 3.76 m (3.94 m). The runway overflights from December 27 have not been included in these means, as the KAREN and ASIRAS elevations have been compared to ALS data from the previous day, as there were no ALS reflections over the runway from December 27. This is most likely due to the fact that all runway overflights were performed at flight elevations of 1000-1500 ft, and above ALS range over a relatively non-reflective surface (no snow). All runway overflights are related with relatively small standard deviations, i.e. ALS-KAREN has 3-4 cm std and ALS-ASIRAS has 5-7 cm. These off-sets have to be applied to all OCOG (TRMFA 50%) retracked ASIRAS and KAREN elevations prior to any analysis using absolute heights.

The second runway overflight on January 15 is visualized in Figure 17 and 18. The along-track comparison of the ALS surface elevations (red) and the KAREN (blue) and ASIRAS (green) TRMFA 50% retracked elevations are shown in Figure 19 top left, together with aircraft roll-angles (black) bottom left. The statistical distribution of the differences between the ALS elevations and KAREN and ASIRAS

are shown in the respective histograms (right). The gaps in the data are related to the data discarded in the analysis due to large roll angles as described above.

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

Table 8. ASIRAS offsets (ALS-ASIRAS) over runways

						OCOG		TRMFA 50%		
Profile	Site	Overflight	Start time UTC	End time UTC	# points	Off- set (m)	Std (m)	Off- set (m)	Std (m)	Roll (%)
A20171226	ROT	1/4	NO ASIRAS DATA							
A20171226	ROT	2/4								
A20171226	ROT	4/4								
A20171227_01	ROT	1/4_26	47852	47867	192	3.79	0.05	4.07	0.04	72
A20171227_01	ROT	2/4_26	48080	48097	221	3.81	0.05	4.09	0.05	91
A20171227_02	ROT	3/4_26	48821	48830	139	3.65	0.05	3.82	0.08	53
A20180109_00	ROT	1/1	64573	64587	420	3.74	0.07	3.92	0.06	92
A20180109_00	ROT	2/2	64746	64758	303	3.74	0.05	3.92	0.05	71
A20180114_00	SKY	1/1	47256	47277	406	3.80	0.06	3.97	0.06	73
A20180115_13	ROT	1/1	PROBLEMS READING DATA							
A20180115_13	ROT	2/2	66978	66993	286	3.77	0.05	3.95	0.05	74

Table 9. KAREN offsets (ALS-KAREN) over runways

Profile	Site	Overflight	Start time	End time	# points	OCOG		TRMFA 50%		Roll (%)
						Off-set (m)	Std (m)	Off-set (m)	Std (m)	
KA20171226_154047	ROT	2/4	56475	56491	155	-0.03	0.03	-0.03	0.03	93
KA20171226_154444	ROT	3/4	56729	56743	165	-0.02	0.03	-0.02	0.03	96
KA20171226_154944	ROT	4/4	57021	57036	152	0.02	0.04	0.03	0.04	88
KA20171227_131721	ROT	1/4_26	47852	47866	125	-0.18	0.03	-0.18	0.04	71
KA20171227_132054	ROT	2/4_26	48081	48096	152	-0.15	0.04	-0.15	0.04	91
KA20171227_133258	ROT	3/4_26	48820	48830	54	-0.14	0.04	-0.14	0.04	52
KA20180109	ROT	1/1	NO KAREN DATA							
KA20180109	ROT	2/2								
KA20180114	SKY	1/1								
+KA20180115_181156	ROT	1/1	66426	66436	149	-0.10	0.04	-0.10	0.03	99
KA20180115_1833804	ROT	2/2	66978	66992	156	0.00	0.04	0.00	0.04	79

Figure 17. ALS elevations model (w.r.t WGS-84) of runway in Rothera, January 15, 2018.

5.7 Horizontal alignment between ASIRAS and KAREN

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

$$dx=+0.98\text{m}, dy=+0.07\text{m}, dz=+0.240\text{m}$$

taken with respect to the aircraft coordinate system as outlined in Figure 7.

In previous CryoVEx campaigns corner reflectors have acted as point targets. If the exact positions of these are known, the radar data can be time-tagged and thus aligned in the along-track direction. For the CryoVEx/KAREN Antarctica campaign calibration was performed along the runway at the Rothera research station. The square-faced trihedral reflectors consisted of: 2 big ones (25 cm long side) at the extremities of the runway and 3 smaller ones (10 cm long side) evenly distributed along the runway (see Figures 19-21). They all have been raised for the ground surface by using wooden supports, resulting on a height of ~55 cm over the surface. The geographical positions of the two bigger reflectors at the ends of the runway have been noted: 67°33'49.5", 68°07'24.8" and 67°34'16.6", 68°07'51.2". Calibration flights were performed on December 26th 2017.

Figure 19: Photo of large corner reflector at Rothera

Figure 20. Photo of smaller corners reflector at Rothera

Figure 21. Disposition of corner reflectors over the runway of the Rothera research station during calibration flight of 26th December 2017. The triangular symbol represents the position of the bigger reflector at one end of the runway (another is at the other end of the runway, not shown in this picture); the circles represent the position of smaller reflectors

Figure 22. Example of preliminary results from the campaign. Range-Doppler maps of data acquired by the two antennas along the calibration track. The corner reflector placed at the end of the runway can be seen on the left half of the images, while the sea ice and icebergs are visible on the right half

5.8 Camera

To complement the analysis of KAREN, ASIRAS and ALS data over sea ice high resolution images are collected along some of the flights. An overview of the properties of the cameras is given in Table 10 and examples are shown in Figure 23-24. Both cameras were remotely controlled and time tagged using the internal camera clock. By combining the time tag of the images with GPS data, the images has be geo-located along the flight lines. Positions of each image are given in a position file, and the raw images are packed in zip-files listed in Appendix 20.

Table 10. Overview of camera types and settings.

Camera type	View	Interval (sec)	Resolution (pixels)	Image size (MB)	Software program	Format
Canon EOS 7D	Slant-looking	12	3456x2304	~1.25	EOS Utility	JPEG
Webcam	Nadir-looking	2	1920x1080	~0.25	-	JPEG

Figure 23. Examples of slant-looking image (#0201) from flight January 12, 2018.

Figure 24. Examples of nadir-looking camera from flight January 15, 2018

6 Calibration and Validation sites

The primary aim of the CryoVEx/KAREN Antarctica 2017/18 campaign was to underfly the CryoSat-2 and SARAL/AltiKa missions and several radar altimeter orbits (ground tracks) were flown during the campaign. Some of these were coordinated with in situ work. All airborne and coordinated in situ data acquisitions along CryoSat-2 and SARAL/AltiKa ground tracks are listed in Table 11, together with information of orbit numbers and passage times. For sea ice flights timing is crucial due to the drift of the ice (few hours), though for land ice flights timing is more relaxed (few days). In the following Sections the main calibration and validation sites are presented, together with first results over sea ice (section 6.1), and land ice (section 6.2).

6.1 Sea Ice

In total, five CryoSat-2 and one SARAL/AltiKa underflights were performed over sea ice (Figure 1 and Table 11) in different regions of the Weddell Sea representing different sea ice types and conditions. For satellite underflights timing is crucial especially over drifting sea ice. This was challenging with respect to both operation hours and weather conditions never the less coincident acquisitions were gathered with in about one hour for the sea ice surveys.

To assist flight planning, information of the sea ice conditions and drift was kindly prepared during the field campaign from repeated SAR images from Sentinel 1a and 1b and distributed to the involved field teams by R. Saldo (DTU Space). An example of a Sentinel-1 SAR image of the Weddell Sea, overlaid with drift information can be seen in Figure 25. Satellite orbit ground tracks from SARAL/AltiKa was kindly provided by A. Guillot (CNES). Such information provides invaluable information to the field team.

Examples of airborne dual frequency altimetry observations (Section 6.1.1) and more details of the field work based out of Schackleton (Section 6.1.2) are presented in the following subsections.

Figure 25. Example of Sentinel-1 SAR image and drift vectors (yellow and cyan) for the Weddell Sea.

Table 10: Overview of airborne data acquisitions along CryoSat-2, Sentinel-3 and SARAL/AltiKa ground tracks, together with information of orbit numbers, passage time, and data acquisition.

Sea ice	Land ice	Location	Airborne Activity	Satellite	Orbit #	passage Date and time (Time given as hh:mm UTC)	ASIRAS	KAREN	ALS	In Situ
X		Weddell Sea near ship	28-12-2017	None	None		X	X	X	X
X		Central Weddell Sea	29-12-2017	CryoSat-2	40953	29-12-2017 13:29	X	X	X	
X		Eastern Weddell Sea	30-12-2017	CryoSat-2	40967	30-12-2017 12:39	X	X	X	
X		Eastern Weddell Sea	30-12-2017	SARAL/AltiKa	539 cycle 115	30-12-2017 10:16	X	X	X	
X		Central Weddell Sea	02-01-2018	CryoSat-2	41011	02-01-2018 13:24	X	X	X	X ¹
X		Western Weddell Sea	06-01-2018	CryoSat-2			X	X	X	
X		Western Weddell Sea	14/15-01-2018	CryoSat-2	41192	15-01-2018 00:36	X	X	X	
	X	-	31-12-2017	CryoSat-2	-	-	x	x	X	
	X	-	31-12-2017	SARAL/AltiKa	-	-	X	X	X	
	X	-	03-01-2018	CryoSat-2	-	-	X	X	X	
	X	-	03-01-2018	SARAL/AltiKa	-	-	X	X	X	
	X	-	10-01-2018	CryoSat-2	-	-	X	-	X	X
	X	-	10-01-2018	SARAL/AltiKa	-	-	X	-	X	
	X	-	13-01-2018	CryoSat-2	-	-	X	X	X	X
	x	-	13-01-2018	SARAL/AltiKa	-	-	X	x	X	X

1) Not directly under the track

6.1.1 Sea Ice in situ data from RRS Ernest Shackleton

The British supply ship RSS Ernest Schackleton kindly provided a base for research activities during the 2017/18 cruise in the Weddell Sea. In total, 14 different sea ice floes were visited. The team consisting of Rachel Tilling (University of Leeds) and Isabel Nias (NASA GSFC) used this opportunity to gather direct ground observations to support the airborne and satellite data acquisitions. The measurement consisted of:

- Sea ice thickness by drilling (an EM32 electromagnetic sensor did not give useful results)
- Snow depth, density, and structure
- Broadband Snow radar (GPR)

The sea ice program was supported by near-real time Sentinel-1 imagery and ice drift velocities by Roberto Saldo, DTU Space, rs@space.dtu.dk, also available at www.seaice.dk and in addition ALOS-2 imagery was provided by Shin-Ichi Sobue, JAXA, sobue.shinichi@jaxa.jp.

Snow depth measurements were also recorded on 13 different sea ice floes as listed in Table 11, twelve of which were in common with the GPR sites. At each floe, snow depths and trenches were sampled and from these locations the depth and stratigraphy of the snow layer was recorded. Between two and six snow pits were sampled on each floe, and from these data the average depth on each flow (Figure 30) and the average depth on all floes (Table 12) was calculated.

The snow depths and stratigraphy are recorded in two accompanying spreadsheets. The snow depth spreadsheet includes the dates and coordinates of each site visited, the snow depth at each site, and the mean depth of snow on each floe. The snow profile spreadsheet describes characteristics of each snow layer for each radar/snow pit location. For the mean depth, latitude and longitude are just the location of the first measurement (hard to get an “average” lat and lon when you’re drifting). “snow-profiles” describes characteristics of each snow layer for each radar/snow pit location. A few missing but that’s also explained in the attached word doc.

Figure 26. A summary of the Ground Penetrating Radar (GPR) shot set taken at each measurement location

GPR measurements were taken on 13 different sea ice floes in the Weddell Sea as listed in Table 11. For each floe, GPR locations were selected either at regular intervals along a transect, or at specific points of interest, depending on the length of the ice floe. At each GPR measurement location, a set of radar shots (Figure 27) was taken. Combining a set of GPR shots in this way allows investigation into the dominant scattering surface of the radar, and the speed of light propagation through the snow on sea ice.

The following GPR location do not have associated snow pit profiles; IS4-GPR2,3,4, IS5-TRANS-GPR0, 25, 50, 75, IS9-GPR2, and IS14-TRANS-GPR 25, 50, 75, 100. At these sites, only the top and bottom of the snowpack was sampled as it was generally shallow and homogeneous.

Table 11. Summary of the measurements taken at each sea ice station in the Weddell Sea.

Sea ice floe station #	Lat S	Lon W	Date/Start time UTC	Comments (snow depth)	Experiments
1	63.7275	16.9147	15/12/2017	(n/a)	<p>“Test” site</p> <p>2 GPR shot sets, no transect</p> <p>Time-limited so no snow pits</p>
2	75.6522	26.8642		(n/a)	
3	76.7767	52.2400	28/12/2017	<p>Fast-ice near the ice shelf front at The Ronne Depot (TRD)</p> <p>Very deep/hard to dig snow (up to 2.8 m deep) which increased time required for each GPR measurement location</p> <p>Sea ice transects performed over a 4-day period</p> <p>Both transects marked-out and overflowed as part of CryoVEx-2017/18 on 28/12/2017 (transect 1 and 2)</p>	<p>4 GPR shot sets along first transect, 50 m apart</p> <p>1 GPR shot set at the end of second transect</p> <p>1 GPR shot set off-transect</p>

				and 29/12/2017 (transect 1 repeat) (183cm)	
4	76.4000	50.8000	1/1/2018	(15.25cm)	4 GPR shot sets, no transect
5	75.6981	45.8331	2/1/2018	Transect marked-out and overflown as part of CryoVEx-2017/18 Nearby (~8 nautical miles) CS-2 orbit also flown Ground team drifted ~1.8 km during a 4-hour station (11.13cm)	4 GPR shot sets a transect, 25 m apart
6	75.7678	45.6992	13/1/2018	(30.25cm)	2 GPR shot sets, no transect
7	72.8331	27.7725	14/1/2018	(14cm)	3 GPR shot sets, no transect
8	72.7336	27.9653	14/1/2018	(13.83cm)	3 GPR shot sets a transect, 25 m apart
9	71.4100	34.2303	15/1/2018	(18.25cm)	2 GPR shot sets, no transect
10	71.1683	35.4678	15/1/2018	(16cm)	2 GPR shot sets, no transect
11	69.4494	40.6236	16/1/2018	(45.2cm)	5 GPR shot sets a transect, 25 m apart
12	69.3947	40.8486	16/1/2018	Uneven transect spacing due to deformation and smaller floe size (25.5cm)	4 GPR shot sets along transect at 0, 25, 46 and 64 m
13	66.6339	45.6047	17/1/2018	(66cm)	2 GPR shot sets, no transect
14	66.3211	45.6781	17/1/2018	(36.67cm)	5 GPR shot sets a transect, 25 m apart

Figure 27. Example of GPR observations.

An example of a **GPR** measurement taken in one of the locations of the campaign is seen in figure 27. It shows how the radar waveform has two peaks, one from the snow surface, and one from within the surface close to the ice surface. The example is for flooded snow which lies about 2 cm above the ice surface.

6.1.2 First results of dual-frequency sea ice observations from KAREN and ASIRAS

The main objective of the CryoVEx/KAREN Ant. 2017/18 campaign is to acquire dual frequency airborne altimetry observation coincident with satellite measurement. One of the key datasets of this campaign were gathered on January 2nd 2018 with underflight of CryoSat-2 coordinated also with in situ observations of the sea ice in the southern part of the Weddell Sea.

An example of the airborne data collected along this flight line is shown in Figure 28. Here, the estimated freeboard (elevation above local sea level) from the three main instruments onboard the Twin Otter aircraft is seen. The raw range observations are converted into elevations relative to the reference ellipsoid (Earth fixed model) as described in section 5. The L1b radar products are retracked (using TFRMA 50%) to give elevations similar to the ALS product. Then the DTU15 mean sea surface (MSS) from O. B. Andersen et al. (2016) is subtracted and the local sea surface anomaly, SSA is estimated and also subtracted. Data is inter-calibrated as described in section 5.6 and the calibrations is refined over open leads. This is valid under the assumption that the radar and laser altimeters are scattered from the same surface for observations of non-penetrating surfaces, such as runways and calm seawater.

The resulting freeboard data, plotted in Figure 28, with respect to the local longitude show as expected that the ALS (near infrared laser) provides the highest freeboard values, the ASIRAS (Ku-band radar) the lowest and KAREN (Ka-band radar) a value in between. The higher spatial resolution of the ALS data is also seen.

Comparing the dataset statistics also confirms this, see Figure 29. For this track, with the chosen method for retracking of radar echoes, the mean freeboard is 44 cm, 36 cm, and 31 cm for ALS, KAREN and ASIRAS respectively. More investigations are needed to refine the analysis w.r.t. optimize the retracking of each radar system preferably including in situ measurement with GPR as described in Section 6.1.2.

Figure 28. Freeboard after MSS and SSA corrections for ALS (blue), ASIRAS (orange), and KAREN (green) altimetry observations January 2, 2018.

Figure 29. Airborne freeboard histograms and related statistics for CryoSat-2 underflight January 2nd 2018.

sea ice.

Table 12. Freeboard statistics corresponding to figure 29.

Freeboard (cm)	Mean	Median	Std. dev
ALS	44.1	34.5	42.0
KAREN	35.5	28.5	36.0
ASIRAS	31.2	23.9	36.3

Figure 30. ALS and ASIRAS difference January 2nd 2018 (top left), and snow depth observations from ASPeCt (Worby et al. 2008) (Adapted from T. Balle, 2020). Bottom: Snow depth from field measurement January 2017-18.

As a first step to further investigate the datasets, we have compared the difference between ALS and ASIRAS freeboard estimates in a study by T. Balle (2020). Figure 28 show the freeboard difference for the January 2nd flight and compare this to snow thickness observation from ASPeCt (Antarctic Sea ice Processes and Climate) observational data (Worby et al. 2008). The ASPeCt dataset is a collection of ship observations made in the period 1981-2005. Table 13 summarizes the statistics and shows that the observed snow depth during ASPeCt is generally lower than the ALS/ASIRAS difference, which correspond to the snow depth under the assumption of Ku-band radar penetration through snow. This assumption depends on the dielectric properties of the snow and needs to be taken with caution for Antarctic conditions.

The mean difference of 16 cm from comparing airborne sensors for 2017/18 conditions, is significantly higher than the 7 cm observed snow depth from the ASPeCt data. This suggests higher snow depth in 2017/18 (almost two decades later as most ASPeCt observations are from 1997/99) and/or under-estimation in the ASPeCt observations as the ships used as bases for sampling prefers to sail in thin ice and open leads in the sea ice. The KAREN-ASIRAS difference falls below the ALS-ASIRAS difference. This corresponds to a main scattering surface from the Ka-band altimetry that is below than the snow/air interface (as observed by ALS). More investigations are needed regarding Ka-band radar penetration and optimal retracking of the signal.

Table 13. Statistics corresponding to Figure 30.

Snow depth (cm)	Mean	Std. dev
ALS-ASIRAS	15.8	8.2
KAREN-ASIRAS	10.2	9.9
ASPeCt	7.2	9.0
Observations 2017-18*	26.6	17.0

*excluding site 1 on fast ice

The airborne data can also be compared to in situ observations made by the team at Schackleton. Examples of GPR observations and snow depth sampling confirm a snow depth in the same order of magnitude as the ALS-ASIRAS difference with an average of 26.6 +/- 17.0 cm (excluding site IS1, which was on fast ice). Similar to a preliminary study in the Arctic with the same instrument setup (Skourup et al. 2019) we find an underestimation of the snow depth from

Figure 31. ALS elevations near Schackleton January 2nd 2018 – zoom in to the left.

combined ALS and ASIRAS data. Again, more detailed studies are needed to investigate the optimal radar retracking, reduced propagation speed of Ku-radar signals in snow etc. Examples of ALS and radar echograms from the repeated flights over the in situ site and Schackleton ship is seen in Figures 30 and 31. These provide the opportunity to do more detailed analysis of point observations to supplement the regional comparisons presented above.

Figure 32. Examples of radar reflections from KAREN (left) and ASIRAS (right) from Schackleton overflight. Reflections from the ship is visible at about waveform no. 220-255 in KAREN data and 8.64×10^4 in the ASIRAS data

6.2 Land ice

The land ice field team operated out of the Summer camp at SkyBlu (See figure 1 for location). 8 sites were visited on the ice sheet and adjacent ice shelf region. The field observations are overflown by the airborne team in the period January 10-14.

6.2.1 In situ data from flights around SkyBlu

The following data were collected:

- Shallow ice cores, up to a maximum depth of 7 meters, to obtain snow density, stratigraphy and chemistry (partly analyzed on-site at Rothera and post-campaign in Cambridge)
- Surface snow density measurements from very shallow snow pits, (top ~ 50 cm), for snow not hard enough to core through.
- Magnaprobe snow depth measurements to first ice layers (maximum depth 120 cm)

The locations of the in-situ sites are shown in Figure 33, along with the near-coincidental CryoSat tracks.

The GPS locations and times of the field sites are shown in Table 14, and an example of the ice core drilling and the Magnaprobe data is shown in Figure 34.

Table 14. Land ice field observations sites

Number	Latitude S	Longitude W	Date/Time UTC	Comments / CryoSat orbit no.	Experiments
1	72 26.63	67 28.92	12 JAN / 17:11	Overflight	Core, snow pit, magna probe
2	73 06.02	67 47.23	12 JAN / 20:55	Overflight	Core, snow pit, magna probe
3	73 30.90	76 21.31	13 JAN / 13:25	Two-aircraft landing, radar reflectors	Core, snow pit, magna probe
4	73 52.30	76 10.13	14 JAN / 13:02	Overflight	Core, snow pit, magna probe
5	72 56.27	70 30.336	14 JAN / 16:30	Overflight nearby	Core, snow pit, magna probe
6	74 46.022	69 31.847	14 JAN / 21:15	Overflight nearby	Core, snow pit, magna probe
7	75 22.598	62 38.612	15 JAN / 13:40	Ronne Ice Shelf	Core, snow pit, magna probe, Ku-band corner reflector for satellite overpass
8	74 54.655	63 35.577	15 JAN / 16:15	Ronne Ice Shelf	Core, snow pit, magna probe

Figure 34. Snow depth observations at site 1.

6.2.2 First results

After collection, all ice cores had their weight and length measured, and the location and thickness of ice lenses in the core were documented (Figure 35). We have performed a preliminary comparison of these ice cores to the RACMO modelled snow melt dataset, which shows the variability in snow density at each site. These results may indicate that the RACMO FDM underestimates firn density and melting in Antarctica.

Figure 36 presents an example of the corresponding echogram for ASIRAS radar for site 6 overflight. Several layers is seen as expected from the core data and shows potential for further investigations with co-analysis of the airborne and surface observations.

Figure 35. In situ ice core data, photographs, compared alongside snow melt from the RACMO model. High density layers in both the cores and modelled results are shown as dark blue.

Figure 36. Radar echograms for ASIRAS at land ice site 6.

Conclusion

The airborne and in situ campaign CryoVEx/KAREN Antarctica 2017-18 acquired extensive datasets of scanning Lidar, Ku- and Ka-band nadir-looking radar, and auxiliary imagery for validation of the ESA CryoSat -2 satellite and the French-Indian SARAL/AltiKa mission. In total nine CryoSat-2 and five AltiKa orbits were underflown during the campaign. The airborne data collection was led by DTU Space with aircraft from British Antarctic Survey and radar instrumentation from MetaSensing and ESA (ASIRAS).

In situ data was gathered using a second Twin-Otter on the ice sheet and shelf regions in the southern Antarctic Peninsula area in the days of January 12 to 16. Shallow ice cores, surface snow density and snow depth observations were collected by the team from Uni. Of Leeds. Also over sea ice, ground observations were carried out with logistical support from the supply cruise in the Weddell Sea by the British vessel Ernest Shackleton. Here, observation of snow depth, radar signatures and other snow and ice properties were collected by another UK team led by University College London.

Initial data analysis shows a dataset with good quality similar to previous CryoVEx campaign in the Arctic. First comparisons of sea ice data show potential for investigations of snow depth determination from different radar and laser frequencies and ice cores from the ice sheet correlate with layers in both airborne and model results.

This report has outlined the collected data and post processing performed and confirms that the goals have been reached. Hence, the scientific community now has a unique dataset from the Antarctic region of coincident dual-frequency airborne and ground observations of both land and sea ice properties coincident with radar altimeter satellite missions: CryoSat-2 and SARAL-AltiKa. The results of this campaign will add to the on-going calibration and validation activities and support development of methods to better exploit observation in the Antarctic region.

7 References

- Andersen, O. B., Stenseng, L., Piccioni, G., & Knudsen, P. (2016). The DTU15 MSS (Mean Sea Surface) and DTU15LAT (Lowest Astronomical Tide) reference surface. Abstract from ESA Living Planet Symposium 2016, Prague, Czech Republic. http://lps16.esa.int/page_session189.php#1579p
- T. Balle, A study of airborne radar penetration into snow cover of sea ice in the Antarctic, Master Thesis, Technical University of Denmark, 2020
- A. Coccia and CK. Macedo, MS-DTU-KAR-03-PFF-030, MetaSensing processing documentations
- Cullen, R.: CryoVEx Airborne Data Products Description, Issue 2.6.1, ESA, Ref. CS-LI-ESA-GS-0371, 2010
- Hvidegaard, S. M., H. Skourup, J. Wilkinson, R. Ladkin, and R. Forsberg: ICE-ARC airborne campaign 2015 - Data collection and processing report, June 2017.
- Skourup, H., S. B. Simonsen, S. L. Sandberg Sørensen, R. Forsberg, and V. Helm (2018a): ESA CryoVEx 2016 spring campaign - Airborne field campaign with ASIRAS radar, and laser scanner measurements. Technical Report, National Space Institute (DTU Space), Technical University of Denmark, ISBN-978-87-91694-41-7
- Skourup, H., S. B. Simonsen, A. Coccia, and R. Forsberg (2018b): ESA CryoVEx/KAREN 2016 fall campaign – First airborne field campaign with combined Ku/Ka-band radars over the EGIG-line with coincident in situ measurements. Technical Report, National Space Institute (DTU Space), Technical University of Denmark
- H. Skourup, A. V. Olesen, L. Sandberg Sørensen, S. Simonsen, S. M. Hvidegaard, N. Hansen, A. F. Olesen, A. Coccia, K. Macedo, V. Helm, R. S. Ladkin, R. Forsberg, A. E. Hogg, I. Ootosaka, A. Shepherd, C. Haas and J. Wilkinson (2019): ESA CryoVEx/KAREN and EU ICE-ARC 2017 - Arctic field campaign with combined airborne Ku/Ka-band radar and laser altimeters, together with extensive in situ measurements over sea- and land ice. Technical Report, National Space Institute (DTU Space), Technical University of Denmark
- Helm, V., A. Humbert, and H. Miller (2014): Elevation and elevation change of Greenland and Antarctica derived from CryoSat-2, *The Cryosphere*, 8, 1539–1559, doi:10.5194/tc-8-1539-2014
- Worby, A. P., Geiger, C. A., Paget, M. J., Van Woert, M. L., Ackley, S. F., & DeLiberty, T. L. (2008). Thickness distribution of Antarctic sea ice. *Journal of Geophysical Research: Oceans*, 113(5), 1-14. <https://doi.org/10.1029/2007JC004254>

8 APPENDIX Operator logs

DOY 360, December 26, 2017: ROT-ROT, Test flight

ALS and ASIRAS:

airborne
laser, egi, gps, altika, asiras working
landed

DOY 361, December 27, 2017: ROT-ROT, Test flight

ALS and ASIRAS:

1258 airborne
laser, egi, gps, altika, asiras working
1340 landed

DOY 362a, December 28, 2017: ROT-Fussil Bluff

ALS and ASIRAS:

1243	take off
	egi not aligned but fom 111
1339	AS, RI rec
1438	landed FBL

DOY 362b, December 28, 2017: Fussil Bluff-TRD

ALS and ASIRAS:

1532 take off, egi nav rdy
1538 AS cal, AS+RI rec
1637 AS+RI new rec
1647 stop rec, climb low clouds
1733 rec AS+RI, 1500-2000 ft due clouds
1843 AS+RI new rec for Shackleton over flight
1905 landed TRD

DOY 363, December 29, 2017: TRD-HAL

ALS and ASIRAS:

1238 airborne
AS cal, AS+RI rec
~1250 overfly Rachel's red line
1350 AS+RI new rec
1355 intercept CS line, 20 min later than sat pass
1445 leaving CS line, AS+RI new rec
1454 descent to 600 ft ice crystals, fog
1505 A23
1515 climb to 1000 ft
1523 descent to 600 ft
1537 stop rec, AS cal
1718 landed HAL

DOY 364, December 30, 2017: HAL-HAL

ALS and ASIRAS:

egi will not align, had to move acft due to frozen skies

0928 airborne
0957 on AL track, open water but soon ice, AS+RI rec
1006 over ice
1013 egi air align
1015 AL pass
fog and broken ice
1038 more dense ice, fog
1041 descent to 800 ft, laser better
1100 AS+RI new rec
1123 turn, descent to 600 ft
1126 climb icing
1130 descent again, 700 ft
1150 climb 1000ft
1200 AS+RI new rec
AS freeze, restart, cal
USB error see photo
install new cable, new usb slot, find driver in win system
1234 AS up and running again
1320 back to HAL, cal
1423 landed

DOY 365, December 31, 2017: HAL-HAL

ALS and ASIRAS:

1020 airborne
1025 AS cal, AS+RI rec
too high for laser, climbing
1045 laser within range
1107 tear drop for laser
1128 AS+RI new rec
1147 CS2 pass
1225 AS+RI new rec
1230 early EOL due bad visibility in HAL
1333 AS+RI new rec
1337 clouds climb
1442 AS shut down
1454 landed

DOY 002, January 2, 2018: HAL-ES-BERKS

ALS and ASIRAS:

Canon left
0953 airborne
AS cal, RI over shelf, no AS
1005 climb, open water, clouds
AS lost GPS (+more error messages)
1040 restart, cal AS
1055 still high, clouds, saving fuel
1108 AS+RI new rec
1208 AS+RI new rec
1251 break line, going to ES
1300-1307 pass ES markers
1325 AS+RI new rec
1335 1200 ft, clouds, no laser
1344 stop Canon
1347 restart Canon
1350 AS no GPS
1400 restart AS, new rec
1440 stop Canon
1453 stop AS, RI, cal
1522 landed Berkner S Dome

1919	airborne
1925	AS cal, rec
	clouds no laser
2005	descent 1000 ft
2025	1300 ft, clouds
2044	AS+RI, new rec
	AS rec stopped! for how long?
2141	AS+RI new rec
2247	climb, stop AS, cal
0037	landed SBR

DOY 005, January 5, 2018: SBR-ROT

ALS and ASIRAS:

1133 airborne, EGI not aligned, weather marginal, air align EGI
1136 EGI FOM 111, nav mode
1148 AS cal, rec, RI no return
1210 descent 1000 ft, RI ok
1218 climb 2000 ft
1223 22 ft, clouds+mountains
1244 1400 ft, AS+RI new rec
mountain waves, unsettled
1315 off-track due clouds, divert to N Sound
1345 too high for LAM, stop rec
high altitude mode Altika test over sea ice in N Sound
1420 AS power fails, inverter?
115V power off for 2 sec, restart EGI, air align
1530 landed

DOY 006, January 6, 2018: ROT-Larsen Triangle-ROT

ALS and ASIRAS:

1405 airborne
AS cal, RI rec
1448 AS rec
1530 Canon left side
1537 -39 open water then sea ice
1545 AS+RI new rec
1655 -----

Page | 65

DOY 009, January 9, 2018: ROT-SkyBlu

ALS and ASIRAS:

1742	start laser
1747	airborne
1752	start asiras, overflight rwy
1802	leave ROT
1804	stop rec, over water
1831	start rec
1940	new recs
	asiras pc 20:18
	UTC 20:24
2029	restart Riegl
2041	stop/start asiras
2127	o/g SkyBlu

DOY 010, January 10, 2018: SkyBlu-SkyBlu

ALS and ASIRAS:

0838	t/o
0843	start asiras
	600 m AGL to CS-2 line
0950	new files
1050	_"
1115	new asiras
1136	riegl error, restart
1155	asiras pc2 error

1212 pc1 non-responsive
1359 close asiras
1401 o/g Rutford ice stream
1509 start taxi
1615 t/o
1639 new files
1714 -"-
1750 climb, low clouds
descend, start scanner
o/g, SkyBlu

DOY 013, January 13, 2018: SBR-SBR

ALS and ASIRAS:

Altika + Canon log
INS air align, forces to take off before alignment

1249 start 'running'
1251 stop
1252 start 'running'
1318 start 'running'
1338 start 'running'
1353 'not config'
- stop
1355 re-send config
-- start 'running' 01131355--
1400 'not config' stop
- re-send config, start, 'running' 01131400--
1407 'not config' stop, re-send config, start, 'running' 01131407--
1412 'not config' stop, re-send config, start, 'running' 01131412--
1414 'not config' stop, re-send config, start, 'running' 01131414--
1417 'not config' stop, re-send config, start, 'running' 01131417--
1438 stop, start 01131438--
1444 'not config' stop, re-send config, start, 'running' 01131444--
1445 'not config' stop, re-send config, start, 'running' 01131445--
1447 'not config' stop, re-send config, start, 'running' 01131447--
1449 'not config' stop, re-send config, start, 'running' 01131449--
~1450 canon on left
1450 restart system
1456 start acq 01131456--
1515 stop/start 01131515--
1519 canon off

1536 stop/start 01131536--
1543 stop, shut down

CryoSat lines

1239 take off

1248 start asiras

1347 new files

1502 new files, over sea ice

1543 UL in situ (Stange Sound), two overflts radar reflector

(1st pass over acft, likely missed reflector)

Maxor GPS at reflector site, and later at acft parking, AH = 12 cm

Asiras S sequence over reflector.

1547 close asiras

1552 landing, await weather at SkyBlu

DOY 014, January 14, 2018: SkyBlu-SkyBlu

ALS and ASIRAS:

1150 start instruments
EGI align - acft movement, NAVRF extended
1155 take off
1158 start asiras
1223 clouds
1254 out of clouds
1307 SkyBlu runway overflight
landing

Weddell Sea CryoSat line

2211 start taxi

2215 take off

start asiras, HAM mode, PC2 chkdesk problems
several reboots, repair XP
2259 lidar stopped due to high altitude transit
2348 SarIn mode auto
2356 SarIn mode tracking
0008 descend, on CS2 line, asiras LAM mode
0100 climb, "asicc" frozen, reboot
0111 flight level 2400 m, enhanced SarIn mode, manual retrack
0135 asiras PC2 error; PC1 frozen, reboot
0140 asiras up again, no "echo obs" and "level" on screen, logged data ok
PC time check:
asiras PC1 01:39
UTC 01:45
0149 new file
0202 clouds
0209 flight level 3800 m, over ice shelf
short asiras files for testing tracking over peninsula
0318 ocean, short asiras sequence, short lidar file
0343 on ground Rothera

DOY 015, January 15, 2018: SkyBlu-SkyBlu

ALS and ASIRAS:

Adelaide Island line and calibration flight

1809 take off
1814 start asiras, LAM mode
1819 hangar overflit
1831 bonner overflit
1836 rwy overflit
flit south of Adelaide Island, clouds
1858 stop asiras, climbing through clouds, too bad viz
1954 landing

9 APPENDIX Coordinates of GPS base stations

Date	DOY	Station	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height (m)
26-12-2017	360	Rothera	-67 33 55.21972	-68 07 40.47369	11.193
27-12-2017	361A	-	-67 33 55.22807	-68 07 40.50110	11.182
	361B	-	-67 33 55.22390	-68 07 40.48739	11.188*
30-12-2017	364	Halley	-75 33 36.51616	-25 34 22.24452	18.787
31-12-2017	365	-	-75 33 37.99480	-25 32 59.95015	19.610
06-01-2018	006	Ref06	-67 33 55.43877	-68 07 39.97582	10.306
10-01-2018	010	Ref10	-74 51 33.82608	-71 34 31.06103	1355.386**
11-01-2018	011	Ref11	-74 51 30.93852	-71 34 29.43432	1359.421
13-01-2018	013	Ref13	-74 51 30.13183	-71 34 33.19678	1357.145

*Averaged

**Corrected

10 APPENDIX Overview of acquired ALS data

Date	DOY	File name	Comment	GPS ant offset	Angles (pitch, roll, heading)	dt (s)
26-12-2017	360	171226_145954_Scanner 1.2dd	Cal Rothera	0.27 0.05 1.55	0.67 -0.25 0.10	-17
27-12-2017	361	171227_125032_Scanner 1.2dd	RW Rothera	0.27 0.05 1.55	0.67 -0.25 0.10	-17
28-12-2017	362	171228_134040_Scanner 1.2dd	R/V Schackelton	0.27 0.05 1.55	0.67 -0.25 0.10	-17
		171228_153045_Scanner 1.2dd				-17
		171228_153653_Scanner 1.2dd				-18
		171228_163739_Scanner 1.2dd				-18
		171228_173331_Scanner 1.2dd				-18
		171228_184415_Scanner 1.2dd				-18
29-12-2017	363	171229_122831_Scanner 1.2dd	R/V Shackleton	0.27 0.05 1.55	0.67 -0.26 0.10	-18
		171229_135019_Scanner 1.2dd	CryoSat track			-18
		171229_144452_Scanner 1.2dd				-18
30-12-2017	364	171230_091935_Scanner 1.2dd	Few data points	-0.28 0.413 1.52	0.67 -0.26 0.10	-18
		171230_095902_Scanner 1.2dd	CryoSat/Altika			-18
		171230_110032_Scanner 1.2dd				-18
		171230_120122_Scanner 1.2dd				-18
31-12-2017	365	171231_100738_Scanner 1.2dd	CryoSat	0.27 0.05 1.55	0.67 -0.27 0.10	-18
		171231_112903_Scanner 1.2dd				-18
		171231_122533_Scanner 1.2dd				-18
		171231_133449_Scanner 1.2dd				-18
02-01-2018	002	180102_093846_Scanner 1.2dd	CryoSat R/V Shackleton	0.27 0.05 1.55	0.67 -0.27 0.10	-17
		180102_095934_Scanner 1.2dd				-17
		180102_110753_Scanner 1.2dd				-18
		180102_093846_Scanner 1.2dd				-18
		180102_093846_Scanner 1.2dd				-18

03-01-2018	003	180103_192004_Scan ner 1.2dd	CryoSat/Altika	0.27 0.05 1.55	0.67 -0.26 0.10	-17
		180103_204520_Scan ner 1.2dd				-17
		180103_214221_Scan ner 1.2dd				-17
05-01-2018	005	180105_112457_Scan ner 1.2dd	No data	0.27 0.05 1.55	0.67 -0.27 0.10	-17
		180105_113404_Scan ner 1.2dd	Altika			-17
		180105_124443_Scan ner 1.2dd				-17
		180105_143606_Scan ner 1.2dd				-617
06-01-2018	006	180106_135246_Scan ner 1.2dd	No data	-0.28 0.413 1.52	0.67 -0.26 0.10	-17
		180106_140219_Scan ner 1.2dd				-17
		180106_154543_Scan ner 1.2dd				-17
		180106_165732_Scan ner 1.2dd				-17
		180106_175140_Scan ner 1.2dd				-17
09-01-2018	009	180109_173108_Scan ner 1.2dd	No data	0.27 0.05 1.55	0.67 -0.25 0.10	-17
		180109_174255_Scan ner 1.2dd	RW Rothera		0.67 -0.26 0.10	-17
		180109_183013_Scan ner 1.2dd	009_gpsegi_29. pos		0.67 -0.26 0.10	-17
		180109_194038_Scan ner 1.2dd			0.67 -0.26 0.10	-17
		180109_203107_Scan ner 1.2dd			0.67 -0.26 0.10	-18
10-01-2018	010	180110_075702_Scan ner 1.2dd	No data	0.27 0.05 1.55	-	-
		180110_083411_Scan ner 1.2dd			0.67 -0.27 0.10	-18
		180110_095121_Scan ner 1.2dd	X12 geogrid		0.67 -0.27 0.10	-18
		180110_105109_Scan ner 1.2dd			0.67 -0.27 0.10	-18
		180110_113815_Scan ner 1.2dd	X12 geogrid		0.67 -0.27 0.10	-18
		180110_135817_Scan ner 1.2dd			0.67 -0.28 0.10	-17
		180110_151037_Scan ner 1.2dd			0.67 -0.28 0.10	-17
		180110_161520_Scan ner 1.2dd	X12 geogrid		0.67 -0.28 0.10	-17
		180110_171345_Scan ner 1.2dd	X12 geogrid		0.67 -0.28 0.10	-17

13-01-2018	013	180113_123555_Scan ner 1.2dd	X12 geogrid	0.27 0.05 1.55	0.67 -0.27 0.10	-18
		180113_134734_Scan ner 1.2dd	Fastis til tjek af roll			-18
		180113_150255_Scan ner 1.2dd				-18
14-01-2018	014	180114_115131_Scan ner 1.2dd	RW SKY, tjek med 009 2031	0.27 0.05 1.55	0.67 -0.27 0.10	-17
		180114_220637_Scan ner 1.2dd			0.67 -0.26 0.10	-17
		180114_234817_Scan ner 1.2dd			0.67 -0.26 0.10	-17
		180115_033159_Scan ner 1.2dd			0.67 -0.26 0.10	-17
15-01-2018	015	180115_180332_Scan ner 1.2dd	Cal Rothera	0.27 0.05 1.55	0.67 -0.25 0.10	-17

11 APPENDIX Overview of acquired ASIRAS data

Date	File name	Start time (UTC)	End time (UTC)	Range window (m)	# Pulses
27-12-2017	A171227_00.log	13:04:54	13:11:00	90.00	914994
	A171227_01.log	13:13:42	13:22:27	90.00	1312492
	A171227_02.log	13:29:42	13:34:17	90.00	687497
28-12-2017	A171228_00.log	13:38:55	14:23:36	90.00	6702456
	A171228_01.log	15:40:40	16:37:33	90.00	8532448
	A171228_02.log	16:37:37	16:45:36	90.00	1197493
	A171228_03.log	17:33:30	18:44:09	90.00	10597428
	A171228_04.log	18:44:18	19:01:22	90.00	2559983
29-12-2017	A171229_00.log	12:41:48	13:50:11	90.00	10257435
	A171229_01.log	13:50:19	14:44:21	90.00	8104945
	A171229_02.log	14:44:26	15:36:58	90.00	7879947
30-12-2017	A171230_00.log	09:33:47	09:34:22	90.00	87499
	A171230_01.log	09:57:18	10:59:44	90.00	9364938
	A171230_02.log	10:59:52	12:00:50	90.00	9144941
	A171230_03.log	12:33:03	13:21:59	90.00	7339951
31-12-2017	A171231_00.log	10:26:24	11:28:24	90.00	9299943
	A171231_01.log	11:28:29	12:25:04	90.00	8487445
	A171231_02.log	12:25:09	13:34:19	90.00	10374930
	A171231_03.log	13:34:23	14:40:39	90.00	9939932
02-01-2018	A180102_00.log	11:08:35	12:10:02	90.00	9217438
	A180102_01.log	12:10:06	13:26:59	90.00	11532422
	A180102_02.log	13:27:03	Missing	90.00	Missing
	A180102_03.log	14:01:03	14:53:59	90.00	7939949
03-01-2018	A180103_00.log	19:26:51	20:44:27	90.00	11639926
	A180103_01.log	20:44:41	21:39:34	90.00	8232446
	A180103_02.log	21:41:09	22:46:44	90.00	9837437
05-01-2018	A180105_00.log	11:50:12	12:44:13	90.00	8102450
	A180105_01.log	12:44:18	13:45:34	90.00	9189940
06-01-2018	A180106_00.log	14:27:47	14:29:38	90.00	277499
	A180106_01.log	14:46:09	15:45:09	90.00	8849944
	A180106_02.log	15:45:13	16:57:03	90.00	10774930
	A180106_03.log	16:57:07	17:51:36	90.00	8172446
	A180106_04.log	17:52:39	18:11:57	90.00	2894981
09-01-2018	A180109_00.log	17:51:51	18:05:06	90.00	1987488
	A180109_01.log	18:30:12	19:39:54	90.00	10454933
	A180109_02.log	19:39:58	20:41:51	90.00	9282440
	A180109_03.log	20:41:56	20:41:58	90.00	5000

	A180109_04.log	20:42:02	20:42:15	90.00	32501
	A180109_05.log	20:42:17	21:22:39	90.00	6054961
10-01-2018	A180110_00.log	08:43:01	09:51:13	90.00	10229936
	A180110_01.log	09:51:24	10:50:58	90.00	8934940
	A180110_02.log	10:51:03	11:15:17	90.00	3634977
	A180110_03.log	11:15:30	Missing	90.00	Missing
	A180110_04.log	14:09:49	15:10:00	90.00	9027444
	A180110_05.log	15:10:05	16:15:11	90.00	9764936
	A180110_06.log	16:15:16	17:45:21	90.00	13512409
13-01-2018	A180113_00.log	12:47:50	13:47:39	90.00	8972444
	A180113_01.log	13:47:49	15:02:47	90.00	11244927
	A180113_02.log	15:02:51	15:42:35	90.00	5959961
14-01-2018	A180114_00.log	11:58:52	13:08:15	90.00	10407436
	A180114_01.log	22:28:26	Missing	18.00	Missing
	A180114_02.log	23:26:34	Missing	18.00	Missing
	A180114_03.log	Missing	Missing	18.00	Missing
	A180114_04.log	23:45:17	00:00:03	18.00	2215004
15-01-2018	A180115_00.log	00:08:11	Missing	90.00	Missing
	A180115_01.log	01:06:51	Missing	18.00	Missing
	A180115_02.log	01:39:25	01:40:46	18.00	202500
	A180115_03.log	01:40:48	01:49:37	18.00	1322491
	A180115_04.log	01:49:40	02:20:19	18.00	4597494
	A180115_05.log	02:28:00	02:31:36	18.00	540001
	A180115_06.log	02:34:03	02:39:03	18.00	749996
	A180115_07.log	02:39:11	02:40:51	18.00	250000
	A180115_08.log	02:44:22	02:46:59	18.00	392499
	A180115_09.log	03:05:56	03:07:47	18.00	277499
	A180115_10.log	03:17:55	03:20:22	18.00	367499
	A180115_11.log	03:22:02	03:23:52	18.00	275000
	A180115_12.log	03:29:18	03:29:40	18.00	55000
	A180115_13.log	18:12:55	18:58:43	90.00	6869958

13 APPENDIX Overview of acquired data from Ka-band radar

Overview for the 26 th Dec 2017: first check flight and calibration acquisitions over Rothera runway.		
#	Notes	Duration
20171226154047	Calibration line –1000 ft AGL	~ 1 min
20171226154444	Calibration line – 1000 ft AGL	~ 1 min
20171226154944	Calibration line – 600 ft	~ 1 min
20171226165826	CAL line Bonner - 600 ft	~ 1 min
20171226160033	CAL line Bonner - 600 ft	~ 1 min
20171226160239	CAL line Bonner - 1000 ft	~ 1 min
20171226160616	CAL line Bonner - 1000 ft	~ 1 min

Overview for the 27 th Dec 2017: second check flight and calib. acquisitions over Rothera runway.		
#	Notes	Duration
20171227131721	Calibration line –1500 ft	~ 1 min
20171227132054	Calibration line –1500 ft	~ 1 min
20171227133258	Calibration line –1000 ft	~ 1 min

Overview for the 28 th Dec 2017: RRS Shackleton overflight		
#	Notes	Duration
20172812133928	Sea ice	8 mins
20172812134754	Sea ice. Bumpy conditions	10 mins
20172812135818	Sea ice	20 mins
20172812141634	Sea ice	10 mins
Refueling		
20172812154021	Ice sheet	30 mins
20172812161203		20 mins
20172812164315		7 mins
Climb up		
20172812180157	Sea ice covered by clouds and fog	20 mins
20172812182701		15 mins
20172812184853		
20172812185058	Transect RRS Shackleton	~ 1 min
20172812185412	Transect RRS Shackleton	~ 1 min
20172812185707	Transect RRS Shackleton	~ 1 min
20172812190016	Transect RRS Shackleton	~ 1 min

Overview for the 29 th Dec 2017: Three Ronne Depot – Halley, Weddell sea, CryoSat		
#	Notes	Duration
20171229124335	RRS Shackleton overflight	~ 1 min
20171229132951	Broken sea ice	4 mins
20171229134512	Broken sea ice	9 mins
20171229135647	Cryostat under flight leg 1	30 mins
20171229142538	Cryostat under flight leg 2	19 mins

20171229144508	Transit over broken sea ice	8 mins
20171229145616	Large iceberg in the sea ice	16 mins
20171229151432	Transit over broken sea ice	23 mins
20171229160151	HAM mode (PRF 2.7 KHz)	3 mins
20171229160637	HAM mode (Bw 300 MHz, PRF 4.1 KHz)	3 mins

30 th Dec 2017: Halley – Halley, Weddell sea, Altika		
#	Notes	Duration
20171230100129	Broken ice (more water than ice) Altika pass	20 mins
20171230102140		20 mins
20171230104139	Lower altitude (800 ft)	22 mins
20171230110402	Lower altitude (600 ft)	7 mins
20171230113103		10 mins
20171230114658	Short before AC drop maneuver	
20171230115204	800 ft	31 mins
20171230123024		
20171230123442	Altika pass	20 mins
20171230130014	700 ft	13 mins
20171230131454		8 mins

31 st Dec 2017: Halley – Halley, Ice sheet		
#	Notes	Duration
20171231104841	Ferry to first waypoint	6 mins
20171231111119	Cryosat line on land ice. quite some pitch sometimes (up to 5 deg). Bumpy	10 mins
20171231112153	Cryosat line on land ice. Cross wind (5-8 deg yaw angle), bumpy. Low cloud	20 mins
20171231114224	Cryosat line on land ice.	20 mins
20171231120257	Cryosat line on land ice.	20 mins
20171231122311	Cryosat line on land ice.	17 mins
20171231124555	Ferry to altika line	10 mins
20171231131907	Altika line	20 mins
20171231133921	Altika line	20 mins
20171231140344	Altika line	8 mins
20171231141306	Ferry back to Halley	10 mins
20171231142325	Ferry back to Halley	10 mins

2 nd Jan 2018: Ronne Ice Shelf		
#	Notes	Duration
20180102111834	Sea ice, broken	20 mins
20180102113908		20 mins
20180102120142		20 mins
20180102122752	Transect	24 mins
20180102125608	Test	
20180102130045	Transect RRS Shackleton	1 min
20180102130327	Transect RRS Shackleton	1 min
20180102130617	Transect RRS Shackleton	1 min
20180102131323	Transect CryoSat	23 mins
20180102134030	Transect CryoSat	20 mins

20180102140234	Transect CryoSat	9 mins
20180102141256	Ferry	10 mins

3rd Jan 2018: Berkner Island South Dome, Alitka		
#	Notes	Duration
20180103195801	Changing flight altitude w.r.t. the ground	2 mins
20180103200322		2 mins
20180103200516		2 mins
20180103200843		20 mins
20180103202948		
20180103204739	AltiKa	30 mins
20180103211838	AltiKa	20 mins
20180103213923	AltiKa	30 mins
20180103221058	AltiKa	30 mins

5th Jan 2018: Ferry from SkyBlu camp to Rothera		
#	Notes	Duration
	Due to unfavorable weather conditions, only few acquisitions have been done for testing purposes, not meaningful from a science point of view.	

6th Jan 2018: Rothera – Rothera, Sea ice		
#	Notes	Duration
20180106150006	Ice shelf	10 mins
20180106152002		10 mins
20180106154023	Sea ice (broken)	5 mins
20180106160018	Sea ice (broken), CryoSat pass	10 mins
20180106161023	Sea ice (broken), CryoSat pass	20 mins
20180106163025	Sea ice (broken), CryoSat pass	10 mins
20180106164043	Sea ice (broken), CryoSat pass	20 mins
20180106170106	Sea ice (broken), CryoSat pass	5 mins
20180106171236	Sea ice and ice shelf	10 mins
20180106172333	Ice shelf and sea ice	10 mins
20180106174109		5 mins
20180106174958		10 mins
20180106180424		3 mins

For the rest of the campaign: see Appendix 9 for acquisition details.

14 APPENDIX File name convention

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

KAREN:

KAR_OPER_Level1b_ SSSSSSSSSSSSSS_ PPPPPPPPPPPPPP_XXXX.nc

SSSSSSSSSSSSSSS Start time given as YYYYMMDDTHHMMSS

PPPPPPPPPPPPPPP Stop time given as YYYYMMDDTHHMMSS

XXXX version of processing, as described in Section 5.5.1, thus XXXX could e.g. be "hamh"

ASIRAS:

AS30AXX_ASIWL1BNNNN_ SSSSSSSSSSSSSS_ PPPPPPPPPPPPPP_0001.DBL

AS30AXX ASIRAS (AS30), AXX number of data log

ASIWL1BNNNN Level 1B data (L1B) processor version (NNNN)

SSSSSSSSSSSSSSS Start time given as YYYYMMDDTHHMMSS

PPPPPPPPPPPPPPP Stop time given as YYYYMMDDTHHMMSS

GPS

GPS_ANT_VER_ SSSSSSSSSSSSSS-PPPPPP_0001.DBL

ANT GPS antenna, e.g. R for rear, and F for front

VER Version

SSSSSSSSSSSSSSS Start time given as YYYYMMDDTHHMMSS

PPPPPP Stop time given as HHMMSS

Inertial Navigation System (INS)

INS_ SSSSSSSSSSSSSS-PPPPPP_0001.DBL

SSSSSSSSSSSSSSS Start time given as YYYYMMDDTHHMMSS

PPPPPP Stop time given as HHMMSS

Airborne laser scanner (ALS) full resolution

ALS_ SSSSSSSSSSSSSS-PPPPPP.nc

SSSSSSSSSSSSSSS Start time given as YYYYMMDDTHHMMSS

PPPPPP Stop time given as HHMMSS

15 APPENDIX Processed GPS data in ESA format

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

Date	DOY	File	Size [MB]
26-12-2017	360	GPS_F_20171226T150118_162053_0001.DBL	0.3
27-12-2017	361	GPS_F_20171227T125534_134228_0001.DBL	0.2
28-12-2017	362	GPS_F_20171228T121054_144029_0001.DBL	0.5
		GPS_F_20171228T151331_190840_0001.DBL	0.8
29-12-2017	363	GPS_F_20171229T122626_172237_0001.DBL	1.1
30-12-2017	364	GPS_G_20171230T094321_142733_0001.DBL	1.1
31-12-2017	365	GPS_F_20171231T100453_145731_0001.DBL	1.0
02-01-2018	2	GPS_F_20180102T093619_152902_0001.DBL	1.3
03-01-2018	3	GPS_F_20180103T185819_244148_0001.DBL	1.2
05-01-2018	5	GPS_F_20180105T112019_153027_0001.DBL	0.9
06-01-2018	6	GPS_G_20180106T134649_185556_0001.DBL	1.1
09-01-2018	9	GPS_F_20180109T172337_213156_0001.DBL	0.9
10-01-2018	10	GPS_F_20180110T083126_121601_0001.DBL	0.8
		GPS_F_20180110T135115_175320_0001.DBL	0.9
13-01-2018	13	GPS_F_20180113T123320_155523_0001.DBL	0.7
14-01-2018	14	GPS_F_20180114T114522_131823_0001.DBL	0.3
		GPS_F_20180114T220255_274558_0001.DBL	1.2
15-01-2018	15	GPS_F_20180115T175334_195654_0001.DBL	0.4

16 APPENDIX Processed INS data in ESA format

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

Date	DOY	File	Size [MB]
26-12-2017	360	INS_20171226T150112_161909_0001.DBL	8
27-12-2017	361	INS_20171227T124814_134005_0001.DBL	5
28-12-2017	362	INS_20171228T123412_143844_0001.DBL	13
		INS_20171228T151625_190713_0001.DBL	24
29-12-2017	363	INS_20171229T122612_172120_0001.DBL	30
30-12-2017	364	INS_20171230T090824_142546_0001.DBL	33
31-12-2017	365	INS_20171231T100527_145615_0001.DBL	30
02-01-2018	2	INS_20180102T093624_152401_0001.DBL	36
03-01-2018	3	INS_20180103T190000_244024_0001.DBL	35
05-01-2018	5	INS_20180105T112812_142624_0001.DBL	18
		INS_20180105T142624_152849_0001.DBL	3
06-01-2018	6	INS_20180106T135013_185400_0001.DBL	31
09-01-2018	9	INS_20180109T172700_213001_0001.DBL	25
10-01-2018	10	INS_20180110T083112_121457_0001.DBL	23
		INS_20180110T134941_175020_0001.DBL	25
13-01-2018	13	INS_20180113T124008_155401_0001.DBL	21
14-01-2018	14	INS_20180114T114500_131649_0001.DBL	9
		INS_20180114T220338_274505_0001.DBL	35
15-01-2018	15	INS_20180115T175519_195513_0001.DBL	12

17 APPENDIX Processed ALS data

Date	DOY	File	Size [MB]
26-12-2017	360	ALS_20171226T151359_155959.nc	59.5
27-12-2017	361	ALS_20171227T125748_133849.nc	80.1
28-12-2017	362	ALS_20171228T134023_143526.nc	288.4
		ALS_20171228T153235_153315.nc	3.6
		ALS_20171228T153636_163718.nc	287.9
		ALS_20171228T163721_164541.nc	29.1
29-12-2017	363	ALS_20171229T123808_134954.nc	166.0
		ALS_20171229T135001_144432.nc	298.0
		ALS_20171229T144435_153644.nc	179.3
30-12-2017	364	ALS_20171230T095844_110011.nc	105.4
		ALS_20171230T110014_120100.nc	155.6
		ALS_20171230T120104_132221.nc	225.6
31-12-2017	365	ALS_20171230T120104_132221.nc	219.2
		ALS_20171231T112846_122513.nc	150.3
		ALS_20171231T122516_133429.nc	295.7
		ALS_20171231T133432_145322.nc	310.1
02-01-2018	002	ALS_20180102T095917_100707.nc	25.3
		ALS_20180102T121014_132709.nc	320.4
		ALS_20180102T132713_145234.nc	358.6
03-01-2018	003	ALS_20180103T191947_202421.nc	87.0
		ALS_20180103T205157_214201.nc	162.2
		ALS_20180103T214204_224849.nc	362.3
05-01-2018	005	ALS_20180105T113614_124424.nc	40.2
		ALS_20180105T124426_134424.nc	33.6
		ALS_20180105T144218_152641.nc	61.3
06-01-2018	006	ALS_20180106T140453_154523.nc	289.8
		ALS_20180106T154527_165711.nc	413.1
		ALS_20180106T165715_175120.nc	261.5
		ALS_20180106T175123_181025.nc	92.7
09-01-2018	009	ALS_20180109T174705_180535.nc	48.8
		ALS_20180109T182956_194017.nc	346.2
		ALS_20180109T194021_202841.nc	256.5
		ALS_20180109T203049_212528.nc	298.8
10-01-2018	010	ALS_20180110T083922_092517.nc	308.0
		ALS_20180110T095103_105049.nc	327.2
		ALS_20180110T105051_113358.nc	231.1
		ALS_20180110T113757_121043.nc	173.3
		ALS_20180110T140242_151016.nc	253.1
		ALS_20180110T151020_161459.nc	362.4
		ALS_20180110T161503_164837.nc	125.7
		ALS_20180110T171329_174754.nc	136.5
13-01-2018	013	ALS_20180113T124028_134713.nc	337.5
		ALS_20180113T134716_150235.nc	424.4

		ALS_20180113T150237_155211.nc	267.1
14-01-2018	014	ALS_20180114T115537_131235.nc	233.4
		ALS_20180114T221546_222346.nc	26.9
		ALS_20180114T240321_250202.nc	12.9
		ALS_20180114T273250_274243.nc	4.5
15-01-2018	015	ALS_20180115T181000_185850.nc	18.5

18APPENDIX Time-tagged and geo-located images

ASCII file	Date	File name of zipped file	File Size (MB)
PIX_slant_20180102.pos	02-01-2018	PIX_slant_20180102T113010-113132.zip	1.4
		PIX_slant_20180102T120246-125952.zip	251.9
		PIX_slant_20180102T130002-135956.zip	285.5
		PIX_slant_20180102T140008-145952.zip	245.0
		PIX_slant_20180102T150002-154340.zip	187.0
PIX_slant_20180106.pos	06-01-2018	PIX_slant_20180106T162902-165956.zip	180.6
		PIX_slant_20180106T170008-175952.zip	394.6
		PIX_slant_20180106T162902-165956.zip	178.0
PIX_slant_20180109.pos	09-01-2018	PIX_slant_20180109T192918-195950.zip	153.4
		PIX_slant_20180109T200002-205958.zip	170.7
		PIX_slant_20180109T210010-214114.zip	172.9
PIX_slant_20180113.pos	13-01-2018	PIX_slant_20180113T160128-161846.zip	72.2
PIX_slant_20180114.pos	14-01-2018	PIX_slant_20180114T010004-015726.zip	297.9
		PIX_slant_20180114T020426-022148.zip	83.1
ASCII file	Date	File name of zipped file	File Size (MB)
PIX_VER_20180109.pos	09-01-2018	PIX_nadir_20180109T193006-195956.zip	57.9
		PIX_nadir_20180109T200000-204102.zip	45.3
PIX_VER_20180113.pos	13-01-2018	PIX_nadir_20180113T155758-155924	2.3
PIX_VER_20180114.pos	14-01-2018	PIX_nadir_20180114T003352-005958.zip	79.2
		PIX_nadir_20180114T010000-015958.zip	276.5
		PIX_nadir_20180114T020000-025958.zip	18.0
		PIX_nadir_20180114T030004-035232.zip	139.2
		PIX_nadir_20180114T043418-044316.zip	22.5
PIX_VER_20180115.pos	15-01-2018	PIX_nadir_20180115T190948-195958.zip	164.5
		PIX_nadir_20180115T200002-200144.zip	3.8

19 APPENDIX Processed KAREN data

Date	DOY	Filename	Size (MB)
26-12-2017	360	KAR_OPER_Level1b_20171226T154047_20171226T154139_levc.nc	11
		KAR_OPER_Level1b_20171226T154444_20171226T154602_levc.nc	19
		KAR_OPER_Level1b_20171226T154944_20171226T155052_levc.nc	15
		KAR_OPER_Level1b_20171226T155827_20171226T155853_levc.nc	7
		KAR_OPER_Level1b_20171226T160034_20171226T160053_levc.nc	6
		KAR_OPER_Level1b_20171226T160240_20171226T160317_levc.nc	8
		KAR_OPER_Level1b_20171226T160617_20171226T160656_levc.nc	10
27-12-2017	361	KAR_OPER_Level1b_20171227T131721_20171227T131755_levc.nc	8
		KAR_OPER_Level1b_20171227T132055_20171227T132201_levc.nc	15
		KAR_OPER_Level1b_20171227T133258_20171227T133354_levc.nc	13
28-12-2017	362	KAR_OPER_Level1b_20171228T133929_20171228T134740_levc.nc	129
		KAR_OPER_Level1b_20171228T134754_20171228T135749_levc.nc	167
		KAR_OPER_Level1b_20171228T135818_20171228T141620_levc.nc	403
		KAR_OPER_Level1b_20171228T141635_20171228T142622_levc.nc	205
		KAR_OPER_Level1b_20171228T154020_20171228T160929_levc.nc	4523
		KAR_OPER_Level1b_20171228T161203_20171228T163156_levc.nc	2013
		KAR_OPER_Level1b_20171228T163415_20171228T164104_levc.nc	441
		KAR_OPER_Level1b_20171228T180157_20171228T182146_levc.nc	657
		KAR_OPER_Level1b_20171228T182701_20171228T184140_levc.nc	882
		KAR_OPER_Level1b_20171228T184853_20171228T184956_levc.nc	14
		KAR_OPER_Level1b_20171228T185058_20171228T185142_levc.nc	11
		KAR_OPER_Level1b_20171228T185413_20171228T185501_levc.nc	10
		KAR_OPER_Level1b_20171228T185707_20171228T185754_levc.nc	11
		KAR_OPER_Level1b_20171228T190016_20171228T190050_levc.nc	7
29-12-2017	363	KAR_OPER_Level1b_20171229T124335_20171229T124423_levc.nc	13
		KAR_OPER_Level1b_20171229T132952_20171229T134337_levc.nc	235
		KAR_OPER_Level1b_20171229T134513_20171229T135448_levc.nc	182
		KAR_OPER_Level1b_20171229T135648_20171229T142526_levc.nc	482
		KAR_OPER_Level1b_20171229T142538_20171229T144335_levc.nc	313
		KAR_OPER_Level1b_20171229T144508_20171229T145310_levc.nc	183
		KAR_OPER_Level1b_20171229T145617_20171229T151321_levc.nc	529
		KAR_OPER_Level1b_20171229T151432_20171229T153705_levc.nc	561
		KAR_OPER_Level1b_20171229T160151_20171229T160428_levc.nc	42
30-12-2017	364	KAR_OPER_Level1b_20171230T160637_20171229T160956_levc.nc	53
		KAR_OPER_Level1b_20171230T102140_20171230T104121_levc.nc	377
		KAR_OPER_Level1b_20171230T104139_20171230T110339_levc.nc	363
		KAR_OPER_Level1b_20171230T110402_20171230T112100_levc.nc	305
		KAR_OPER_Level1b_20171230T113103_20171230T114104_levc.nc	312
		KAR_OPER_Level1b_20171230T114658_20171230T114901_levc.nc	30
		KAR_OPER_Level1b_20171230T115204_20171230T122332_levc.nc	816
		KAR_OPER_Level1b_20171230T123025_20171230T123246_levc.nc	42
		KAR_OPER_Level1b_20171230T123443_20171230T125444_levc.nc	327
		KAR_OPER_Level1b_20171230T130014_20171230T131305_levc.nc	214

		KAR_OPER_Level1b_20171230T131454_20171230T132151_levc.nc	113
31-12-2017	365	KAR_OPER_Level1b_20171231T104841_20171231T105439_levc.nc	121
		KAR_OPER_Level1b_20171231T111120_20171231T112124_levc.nc	1041
		KAR_OPER_Level1b_20171231T112153_20171231T114148_levc.nc	1617
		KAR_OPER_Level1b_20171231T114224_20171231T120237_levc.nc	1600
		KAR_OPER_Level1b_20171231T120258_20171231T122252_levc.nc	691
		KAR_OPER_Level1b_20171231T122311_20171231T124035_levc.nc	750
		KAR_OPER_Level1b_20171231T124555_20171231T125528_levc.nc	406
		KAR_OPER_Level1b_20171231T131908_20171231T133903_levc.nc	2189
		KAR_OPER_Level1b_20171231T133922_20171231T140003_levc.nc	2182
		KAR_OPER_Level1b_20171231T140344_20171231T141111_levc.nc	684
		KAR_OPER_Level1b_20171231T141306_20171231T142303_levc.nc	646
		KAR_OPER_Level1b_20171231T142325_20171231T143324_levc.nc	242
02-01-2018	2	KAR_OPER_Level1b_20180102T111835_20180102T113827_levc.nc	382
		KAR_OPER_Level1b_20180102T113908_20180102T115846_levc.nc	343
		KAR_OPER_Level1b_20180102T120142_20180102T122140_levc.nc	400
		KAR_OPER_Level1b_20180102T122752_20180102T125101_levc.nc	346
		KAR_OPER_Level1b_20180102T125608_20180102T125705_levc.nc	13
		KAR_OPER_Level1b_20180102T130045_20180102T130247_levc.nc	45
		KAR_OPER_Level1b_20180102T130327_20180102T130355_levc.nc	7
		KAR_OPER_Level1b_20180102T130617_20180102T130643_levc.nc	6
		KAR_OPER_Level1b_20180102T131323_20180102T133522_levc.nc	576
		KAR_OPER_Level1b_20180102T134030_20180102T140029_levc.nc	492
		KAR_OPER_Level1b_20180102T140135_20180102T141036_levc.nc	149
		KAR_OPER_Level1b_20180102T141257_20180102T142253_levc.nc	182
03-01-2018	3	KAR_OPER_Level1b_20180103T195802_20180103T195958_levc.nc	39
		KAR_OPER_Level1b_20180103T200322_20180103T200412_levc.nc	13
		KAR_OPER_Level1b_20180103T200516_20180103T200656_levc.nc	39
		KAR_OPER_Level1b_20180103T200843_20180103T202831_levc.nc	452
		KAR_OPER_Level1b_20180103T202948_20180103T204214_levc.nc	235
		KAR_OPER_Level1b_20180103T204739_20180103T211732_levc.nc	614
		KAR_OPER_Level1b_20180103T211839_20180103T213842_levc.nc	306
		KAR_OPER_Level1b_20180103T213923_20180103T221024_levc.nc	610
		KAR_OPER_Level1b_20180103T221058_20180103T224055_levc.nc	543
05-01-2018	5	KAR_OPER_Level1b_20180105T121052_20180105T121313_levc.nc	60
		KAR_OPER_Level1b_20180105T131856_20180105T132348_levc.nc	440
		KAR_OPER_Level1b_20180105T132708_20180105T132721_levc.nc	4
		KAR_OPER_Level1b_20180105T132756_20180105T132848_levc.nc	25
		KAR_OPER_Level1b_20180105T133443_20180105T133532_levc.nc	15
		KAR_OPER_Level1b_20180105T133622_20180105T133732_levc.nc	21
06-01-2018	6	KAR_OPER_Level1b_20180106T150006_20180106T151001_levc.nc	699
		KAR_OPER_Level1b_20180106T152002_20180106T152957_levc.nc	199
		KAR_OPER_Level1b_20180106T154023_20180106T154556_levc.nc	103
		KAR_OPER_Level1b_20180106T160019_20180106T161007_levc.nc	142
		KAR_OPER_Level1b_20180106T161023_20180106T163011_levc.nc	293
		KAR_OPER_Level1b_20180106T163026_20180106T164022_levc.nc	146
		KAR_OPER_Level1b_20180106T164043_20180106T170040_levc.nc	318
		KAR_OPER_Level1b_20180106T170106_20180106T170639_levc.nc	82
		KAR_OPER_Level1b_20180106T171237_20180106T172212_levc.nc	208

		KAR_OPER_Level1b_20180106T172334_20180106T173239_levc.nc	205
		KAR_OPER_Level1b_20180106T174110_20180106T174608_levc.nc	78
		KAR_OPER_Level1b_20180106T174958_20180106T175946_levc.nc	206
		KAR_OPER_Level1b_20180106T180424_20180106T180719_levc.nc	50
13-01-2018	13	KAR_OPER_Level1b_20180113T124912_20180113T125146_levc.nc	46
		KAR_OPER_Level1b_20180113T125217_20180113T131817_levc.nc	1864
		KAR_OPER_Level1b_20180113T131937_20180113T133825_levc.nc	2093
		KAR_OPER_Level1b_20180113T133854_20180113T135147_levc.nc	1117
		KAR_OPER_Level1b_20180113T135517_20180113T135937_levc.nc	227
		KAR_OPER_Level1b_20180113T140040_20180113T140533_levc.nc	264
		KAR_OPER_Level1b_20180113T140734_20180113T141109_levc.nc	87
		KAR_OPER_Level1b_20180113T141211_20180113T141415_levc.nc	33
		KAR_OPER_Level1b_20180113T141451_20180113T141635_levc.nc	28
		KAR_OPER_Level1b_20180113T141737_20180113T143758_levc.nc	812
		KAR_OPER_Level1b_20180113T143811_20180113T144257_levc.nc	83
		KAR_OPER_Level1b_20180113T144411_20180113T144511_levc.nc	17
		KAR_OPER_Level1b_20180113T144542_20180113T144646_levc.nc	16
		KAR_OPER_Level1b_20180113T144748_20180113T144834_levc.nc	13
		KAR_OPER_Level1b_20180113T144915_20180113T144954_levc.nc	11
		KAR_OPER_Level1b_20180113T145650_20180113T151504_levc.nc	749
		KAR_OPER_Level1b_20180113T151521_20180113T153632_levc.nc	2078
		KAR_OPER_Level1b_20180113T153658_20180113T154324_levc.nc	196
14-01-2018	14	KAR_OPER_Level1b_20180114T115844_20180114T121806_levc.nc	3144
		KAR_OPER_Level1b_20180114T122059_20180114T124023_levc.nc	1774
		KAR_OPER_Level1b_20180114T124037_20180114T124818_levc.nc	390
		KAR_OPER_Level1b_20180114T124951_20180114T125150_levc.nc	47
		KAR_OPER_Level1b_20180114T125247_20180114T125427_levc.nc	38
		KAR_OPER_Level1b_20180114T130725_20180114T130729_levc.nc	1
15-01-2018	15	KAR_OPER_Level1b_20180115T002138_20180115T003210_levc.nc	161
		KAR_OPER_Level1b_20180115T003258_20180115T003432_levc.nc	23
		KAR_OPER_Level1b_20180115T003501_20180115T003657_levc.nc	31
		KAR_OPER_Level1b_20180115T003726_20180115T003837_levc.nc	17
		KAR_OPER_Level1b_20180115T003918_20180115T004018_levc.nc	15
		KAR_OPER_Level1b_20180115T004159_20180115T004652_levc.nc	74
		KAR_OPER_Level1b_20180115T004801_20180115T005021_levc.nc	34
		KAR_OPER_Level1b_20180115T005114_20180115T005248_levc.nc	24
		KAR_OPER_Level1b_20180115T005314_20180115T005501_levc.nc	28
		KAR_OPER_Level1b_20180115T181156_20180115T183151_levc.nc	2402
		KAR_OPER_Level1b_20180115T183223_20180115T183804_levc.nc	370
		KAR_OPER_Level1b_20180115T184538_20180115T184835_levc.nc	90
		KAR_OPER_Level1b_20180115T185827_20180115T190408_levc.nc	822
		KAR_OPER_Level1b_20180115T191328_20180115T191737_levc.nc	628

20 APPENDIX Processed ASIRAS data

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

Date	DOY	File name	Size (MB)
27-12-2017	361	AS6OA00_ASIWL1B040320171227T130454_20171227T131100_0001.DBL	5.1
		AS6OA01_ASIWL1B040320171227T131342_20171227T132227_0001.DBL	7.1
		AS6OA02_ASIWL1B040320171227T132942_20171227T133417_0001.DBL	5.2
28-12-2017	362	AS6OA00_ASIWL1B040320171228T133855_20171228T142336_0001.DBL	65.6
		AS6OA01_ASIWL1B040320171228T154040_20171228T163733_0001.DBL	82.6
		AS6OA02_ASIWL1B040320171228T163737_20171228T164536_0001.DBL	9.9
		AS6OA03_ASIWL1B040320171228T173330_20171228T184409_0001.DBL	70.7
		AS6OA04_ASIWL1B040320171228T184418_20171228T190122_0001.DBL	20.1
29-12-2017	363	AS6OA00_ASIWL1B040320171229T124148_20171229T135011_0001.DBL	72.3
		AS6OA01_ASIWL1B040320171229T135019_20171229T144421_0001.DBL	81.3
		AS6OA02_ASIWL1B040320171229T144426_20171229T153658_0001.DBL	77.2
30-12-2017	364	AS6OA00_ASIWL1B040320171230T093347_20171230T093422_0001.DBL	0.47
		AS6OA01_ASIWL1B040320171230T095718_20171230T105944_0001.DBL	97.9
		AS6OA02_ASIWL1B040320171230T105952_20171230T120050_0001.DBL	109.0
		AS6OA03_ASIWL1B040320171230T123303_20171230T132159_0001.DBL	70.6
31-12-2017	365	AS6OA00_ASIWL1B040320171231T102624_20171231T112824_0001.DBL	69.9
		AS6OA01_ASIWL1B040320171231T112829_20171231T122504_0001.DBL	71.7
		AS6OA02_ASIWL1B040320171231T122509_20171231T133419_0001.DBL	111
		AS6OA03_ASIWL1B040320171231T133423_20171231T144039_0001.DBL	97.5
02-01-2018	2	AS6OA00_ASIWL1B040320180102T110835_20180102T121002_0001.DBL	92.5
		AS6OA01_ASIWL1B040320180102T121006_20180102T132659_0001.DBL	109

		AS6OA02_ASIWL1B040320180102T132703_20180102T135426_0001.DBL	44.2
		AS6OA03_ASIWL1B040320180102T140103_20180102T145359_0001.DBL	67.9
03-01-2018	3	AS6OA00_ASIWL1B040320180103T192651_20180103T204427_0001.DBL	90.6
		AS6OA01_ASIWL1B040320180103T204441_20180103T213934_0001.DBL	66.8
		AS6OA02_ASIWL1B040320180103T214109_20180103T224644_0001.DBL	95.6
05-01-2018	5	AS6OA00_ASIWL1B040320180105T115012_20180105T124413_0001.DBL	79.9
		AS6OA01_ASIWL1B040320180105T124418_20180105T134534_0001.DBL	61.9
06-01-2018	6	AS6OA00_ASIWL1B040320180106T142747_20180106T142938_0001.DBL	1.9
		AS6OA01_ASIWL1B040320180106T144609_20180106T154509_0001.DBL	93.7
		AS6OA02_ASIWL1B040320180106T154513_20180106T165703_0001.DBL	101
		AS6OA03_ASIWL1B040320180106T165707_20180106T175136_0001.DBL	73.6
		AS6OA04_ASIWL1B040320180106T175239_20180106T181157_0001.DBL	24
09-01-2018	9	AS6OA00_ASIWL1B040320180109T175151_20180109T180506_0001.DBL	20.7
		AS6OA01_ASIWL1B040320180109T183012_20180109T193954_0001.DBL	110
		AS6OA02_ASIWL1B040320180109T193958_20180109T204151_0001.DBL	128
		AS6OA03_ASIWL1B040320180109T204156_20180109T204158_0001.DBL	0.03
		AS6OA04_ASIWL1B040320180109T204202_20180109T204215_0001.DBL	0.5
		AS6OA05_ASIWL1B040320180109T204217_20180109T212239_0001.DBL	84
10-01-2018	10	AS6OA00_ASIWL1B040320180110T084301_20180110T095113_0001.DBL	91
		AS6OA01_ASIWL1B040320180110T095124_20180110T105058_0001.DBL	90.5
		AS6OA02_ASIWL1B040320180110T105103_20180110T111517_0001.DBL	30.5
		AS6OA03_ASIWL1B040320180110T111530_20180110T115254_0001.DBL	56.3
		AS6OA04_ASIWL1B040320180110T140949_20180110T151000_0001.DBL	74.2
		AS6OA05_ASIWL1B040320180110T151005_20180110T161511_0001.DBL	91.8
		AS6OA06_ASIWL1B040320180110T161516_20180110T174521_0001.DBL	100

13-01-2018	13	AS6OA00_ASIWL1B040320180113T124750_20180113T134739_0001.DBL	79.7
		AS6OA01_ASIWL1B040320180113T134749_20180113T150247_0001.DBL	115
		AS6OA02_ASIWL1B040320180113T150251_20180113T154235_0001.DBL	61.6
14-01-2018	14	AS6OA00_ASIWL1B040320180114T115852_20180114T130815_0001.DBL	84.3
		AS6OA02_ASIHL1B040320180114T232634_20180114T234051_0001.DBL	12.4
		AS6OA04_ASIHL1B040320180114T234517_20180114T240003_0001.DBL	0
15-01-2018	15	AS6OA00_ASIWL1B040320180115T000811_20180115T005935_0001.DBL	75.4
		AS6OA01_ASIHL1B040320180115T010651_20180115T013457_0001.DBL	23
		AS6OA02_ASIHL1B040320180115T013925_20180115T014046_0001.DBL	1.67
		AS6OA03_ASIHL1B040320180115T014048_20180115T014937_0001.DBL	10.4
		AS6OA04_ASIHL1B040320180115T014940_20180115T022019_0001.DBL	25
		AS6OA05_ASIHL1B040320180115T022800_20180115T023136_0001.DBL	4.65
		AS6OA06_ASIHL1B040320180115T023403_20180115T023903_0001.DBL	6.96
		AS6OA07_ASIHL1B040320180115T023911_20180115T024051_0001.DBL	2.3
		AS6OA07_ASIHL1B040320180115T023911_20180115T024051_0001.DBL	3.48
		AS6OA09_ASIHL1B040320180115T030556_20180115T030747_0001.DBL	2.62
		AS6OA10_ASIHL1B040320180115T031755_20180115T032022_0001.DBL	3.34
		AS6OA11_ASIHL1B040320180115T032202_20180115T032352_0001.DBL	2.84
		AS6OA12_ASIHL1B040320180115T032918_20180115T032940_0001.DBL	0.79
		AS6OA13_ASIWL1B040320180115T181255_20180115T185843_0001.DBL	47.2

21 APPENDIX Final ASIRAS profiles

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

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

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

A171227_00

AS60A00_AS1W1B040320171227T130454_20171227T131100_0001.DBL

Date	2017-12-27	Instrument Mode	Adv. Low Altitude
Start Time	13:04:56 (47096)	Aircraft	BAS Twin Otter
Stop Time	13:11:01 (47461)	Retracker	OCOG
Distance	21.737 km	INS Resolution	50 Hz
Duration	00 h 06 m 06 s	Processor Version	0403

A171227_01

AS60A01_AS1W1B040320171227T131342_20171227T132227_0001.DBL

Date	2017-12-27	Instrument Mode	Adv. Low Altitude
Start Time	13:13:44 (47624)	Aircraft	BAS Twin Otter
Stop Time	13:22:27 (48147)	Retracker	OCOG
Distance	30.822 km	INS Resolution	50 Hz
Duration	00 h 08 m 44 s	Processor Version	0403

A171227_02

AS60A02_AS1W1B040320171227T132942_20171227T133417_0001.DBL

Date	2017-12-27	Instrument Mode	Adv. Low Altitude
Start Time	13:29:44 (48584)	Aircraft	BAS Twin Otter
Stop Time	13:34:18 (48858)	Retracker	OCOG
Distance	16.024 km	INS Resolution	50 Hz
Duration	00 h 04 m 35 s	Processor Version	0403

A171228_00

AS60A00_AS1W1B040320171228T133855_20171228T142336_0001.DBL

Date	2017-12-28	Instrument Mode	Adv. Low Altitude
Start Time	13:38:57 (49137)	Aircraft	BAS Twin Otter
Stop Time	14:23:37 (51817)	Retracker	OCOG
Distance	169.398 km	INS Resolution	50 Hz
Duration	00 h 44 m 41 s	Processor Version	0403

A171228_01

AS60A01_AS1W1B040320171228T154040_20171228T163733_0001.DBL

Date	2017-12-28	Instrument Mode	Adv. Low Altitude
Start Time	15:40:42 (56442)	Aircraft	BAS Twin Otter
Stop Time	16:37:34 (59854)	Retracker	OCOG
Distance	219.746 km	INS Resolution	50 Hz
Duration	00 h 56 m 53 s	Processor Version	0403

A171228_02

AS60A02_AS1W1B040320171228T163737_20171228T164536_0001.DBL

Date	2017-12-28	Instrument Mode	Adv. Low Altitude
Start Time	16:37:39 (59859)	Aircraft	BAS Twin Otter
Stop Time	16:45:37 (60337)	Retracker	OCOG
Distance	31.867 km	INS Resolution	50 Hz
Duration	00 h 07 m 58 s	Processor Version	0403

A171228_03

AS60A03_AS1W1B040320171228T173330_20171228T184409_0001.DBL

Date	2017-12-28	Instrument Mode	Adv. Low Altitude
Start Time	17:33:32 (63212)	Aircraft	BAS Twin Otter
Stop Time	18:44:10 (67450)	Retracker	OCOG
Distance	276.501 km	INS Resolution	50 Hz
Duration	01 h 10 m 39 s	Processor Version	0403

A171228_04

AS60A04_AS1W1B040320171228T184418_20171228T190122_0001.DBL

Date	2017-12-28	Instrument Mode	Adv. Low Altitude
Start Time	18:44:20 (67460)	Aircraft	BAS Twin Otter
Stop Time	19:01:23 (68483)	Retracker	OCOG
Distance	57.416 km	INS Resolution	50 Hz
Duration	00 h 17 m 03 s	Processor Version	0403

A171229_00

AS60A00_AS1W1B040320171229T124148_20171229T135011_0001.DBL

Date	2017-12-29	Instrument Mode	Adv. Low Altitude
Start Time	12:41:50 (45710)	Aircraft	BAS Twin Otter
Stop Time	13:50:12 (49812)	Retracker	OCOG
Distance	250.733 km	INS Resolution	50 Hz
Duration	01 h 08 m 23 s	Processor Version	0403

A171229_01

AS60A01_AS1W1B040320171229T135019_20171229T144421_0001.DBL

Date	2017-12-29	Instrument Mode	Adv. Low Altitude
Start Time	13:50:21 (49821)	Aircraft	BAS Twin Otter
Stop Time	14:44:22 (53062)	Retracker	OCOG
Distance	205.712 km	INS Resolution	50 Hz
Duration	00 h 54 m 02 s	Processor Version	0403

A171229_02

AS60A02_AS1W1B040320171229T144426_20171229T153658_0001.DBL

Date	2017-12-29	Instrument Mode	Adv. Low Altitude
Start Time	14:44:28 (53068)	Aircraft	BAS Twin Otter
Stop Time	15:36:59 (56219)	Retracker	OCOG
Distance	180.419 km	INS Resolution	50 Hz
Duration	00 h 52 m 32 s	Processor Version	0403

A171230_00

AS60A00_AS1W1B040320171230T093347_20171230T093422_0001.DBL

Date	2017-12-30	Instrument Mode	Adv. Low Altitude
Start Time	09:33:49 (34429)	Aircraft	BAS Twin Otter
Stop Time	09:34:23 (34463)	Retracker	OCOG
Distance	2.462 km	INS Resolution	50 Hz
Duration	00 h 00 m 34 s	Processor Version	0403

A171230_01

AS60A01_AS1W1B040320171230T095718_20171230T105944_0001.DBL

Date	2017-12-30	Instrument Mode	Adv. Low Altitude
Start Time	09:57:20 (35840)	Aircraft	BAS Twin Otter
Stop Time	10:59:45 (39585)	Retracker	OCOG
Distance	233.975 km	INS Resolution	50 Hz
Duration	01 h 02 m 26 s	Processor Version	0403

A171230_02

AS60A02_AS1W1B040320171230T105952_20171230T120050_0001.DBL

Date	2017-12-30	Instrument Mode	Adv. Low Altitude
Start Time	10:59:54 (39594)	Aircraft	BAS Twin Otter
Stop Time	12:00:51 (43251)	Retracker	OCOG
Distance	231.723 km	INS Resolution	50 Hz
Duration	01 h 00 m 58 s	Processor Version	0403

A171230_03

AS60A03_AS1W1B040320171230T123303_20171230T132159_0001.DBL

Date	2017-12-30	Instrument Mode	Adv. Low Altitude
Start Time	12:33:05 (45185)	Aircraft	BAS Twin Otter
Stop Time	13:22:00 (48120)	Retracker	OCOG
Distance	177.363 km	INS Resolution	50 Hz
Duration	00 h 48 m 56 s	Processor Version	0403

A171231_00

AS60A00_AS1W1B040320171231T102624_20171231T112824_0001.DBL

Date	2017-12-31	Instrument Mode	Adv. Low Altitude
Start Time	10:26:26 (37586)	Aircraft	BAS Twin Otter
Stop Time	11:28:25 (41305)	Retracker	OCOG
Distance	232.736 km	INS Resolution	50 Hz
Duration	01 h 01 m 60 s	Processor Version	0403

A171231_01

AS60A01_AS1W1B040320171231T112829_20171231T122504_0001.DBL

Date	2017-12-31	Instrument Mode	Adv. Low Altitude
Start Time	11:28:31 (41311)	Aircraft	BAS Twin Otter
Stop Time	12:25:05 (44705)	Retracker	OCOG
Distance	201.299 km	INS Resolution	50 Hz
Duration	00 h 56 m 35 s	Processor Version	0403

A171231_02

AS60A02_AS1W1B040320171231T122509_20171231T133419_0001.DBL

Date	2017-12-31	Instrument Mode	Adv. Low Altitude
Start Time	12:25:11 (44711)	Aircraft	BAS Twin Otter
Stop Time	13:34:20 (48860)	Retracker	OCOG
Distance	274.613 km	INS Resolution	50 Hz
Duration	01 h 09 m 10 s	Processor Version	0403

A171231_03

AS60A03_AS1W1B040320171231T133423_20171231T144039_0001.DBL

Date	2017-12-31	Instrument Mode	Adv. Low Altitude
Start Time	13:34:25 (48865)	Aircraft	BAS Twin Otter
Stop Time	14:40:40 (52840)	Retracker	OCOG
Distance	259.125 km	INS Resolution	50 Hz
Duration	01 h 06 m 16 s	Processor Version	0403

A180102_00

AS60A00_AS1W1B040320180102T110835_20180102T121002_0001.DBL

Date	2018-01-02	Instrument Mode	Adv. Low Altitude
Start Time	11:08:37 (40117)	Aircraft	BAS Twin Otter
Stop Time	12:10:03 (43803)	Retracker	OCOG
Distance	237.453 km	INS Resolution	50 Hz
Duration	01 h 01 m 26 s	Processor Version	0403

A180102_01

AS60A01_AS1W1B040320180102T121006_20180102T132659_0001.DBL

Date	2018-01-02	Instrument Mode	Adv. Low Altitude
Start Time	12:10:08 (43808)	Aircraft	BAS Twin Otter
Stop Time	13:27:01 (48421)	Retracker	OCOG
Distance	285.256 km	INS Resolution	50 Hz
Duration	01 h 16 m 53 s	Processor Version	0403

A180102_02

AS60A02_AS1W1B040320180102T132703_20180102T135426_0001.DBL

Date	2018-01-02	Instrument Mode	Adv. Low Altitude
Start Time	13:27:05 (48425)	Aircraft	BAS Twin Otter
Stop Time	13:54:28 (50068)	Retracker	OCOG
Distance	98.318 km	INS Resolution	50 Hz
Duration	00 h 27 m 23 s	Processor Version	0403

A180102_03

AS60A03_AS1W1B040320180102T140103_20180102T145359_0001.DBL

Date	2018-01-02	Instrument Mode	Adv. Low Altitude
Start Time	14:01:05 (50465)	Aircraft	BAS Twin Otter
Stop Time	14:53:59 (53639)	Retracker	OCOG
Distance	192.811 km	INS Resolution	50 Hz
Duration	00 h 52 m 55 s	Processor Version	0403

A180103_00

AS60A00_AS1W1B040320180103T192651_20180103T204427_0001.DBL

Date	2018-01-03	Instrument Mode	Adv. Low Altitude
Start Time	19:26:53 (70013)	Aircraft	BAS Twin Otter
Stop Time	20:44:28 (74668)	Retracker	OCOG
Distance	291.544 km	INS Resolution	50 Hz
Duration	01 h 17 m 36 s	Processor Version	0403

A180103_01

AS60A01_ASIM1B040320180103T204441_20180103T213934_0001.DBL

Date	2018-01-03	Instrument Mode	Adv. Low Altitude
Start Time	20:44:43 (74683)	Aircraft	BAS Twin Otter
Stop Time	21:39:35 (77975)	Retracker	OCOG
Distance	194.736 km	INS Resolution	50 Hz
Duration	00 h 54 m 53 s	Processor Version	0403

A180103_02

AS60A02_ASIM1B040320180103T214109_20180103T224644_0001.DBL

Date	2018-01-03	Instrument Mode	Adv. Low Altitude
Start Time	21:41:11 (78071)	Aircraft	BAS Twin Otter
Stop Time	22:46:45 (82005)	Retracker	OCOG
Distance	245.637 km	INS Resolution	50 Hz
Duration	01 h 05 m 34 s	Processor Version	0403

A180105_00

AS60A00_ASIM1B040320180105T115012_20180105T124413_0001.DBL

Date	2018-01-05	Instrument Mode	Adv. Low Altitude
Start Time	11:50:14 (42614)	Aircraft	BAS Twin Otter
Stop Time	12:44:15 (45855)	Retracker	OCOG
Distance	267.291 km	INS Resolution	50 Hz
Duration	00 h 54 m 01 s	Processor Version	0403

A180105_01

AS60A01_ASIM1B040320180105T124418_20180105T134534_0001.DBL

Date	2018-01-05	Instrument Mode	Adv. Low Altitude
Start Time	12:44:20 (45860)	Aircraft	BAS Twin Otter
Stop Time	13:45:35 (49535)	Retracker	OCOG
Distance	285.545 km	INS Resolution	50 Hz
Duration	01 h 01 m 15 s	Processor Version	0403

A180106_00

AS60A00_AS1W1B040320180106T142747_20180106T142938_0001.DBL

Date	2018-01-06	Instrument Mode	Adv. Low Altitude
Start Time	14:27:49 (52069)	Aircraft	BAS Twin Otter
Stop Time	14:29:39 (52179)	Retracker	OCOG
Distance	7.602 km	INS Resolution	50 Hz
Duration	00 h 01 m 51 s	Processor Version	0403

A180106_01

AS60A01_AS1W1B040320180106T144609_20180106T154509_0001.DBL

Date	2018-01-06	Instrument Mode	Adv. Low Altitude
Start Time	14:46:11 (53171)	Aircraft	BAS Twin Otter
Stop Time	15:45:10 (56710)	Retracker	OCOG
Distance	240.212 km	INS Resolution	50 Hz
Duration	00 h 58 m 60 s	Processor Version	0403

A180106_02

AS60A02_AS1W1B040320180106T154513_20180106T165703_0001.DBL

Date	2018-01-06	Instrument Mode	Adv. Low Altitude
Start Time	15:45:15 (56715)	Aircraft	BAS Twin Otter
Stop Time	16:57:04 (61024)	Retracker	OCOG
Distance	265.259 km	INS Resolution	50 Hz
Duration	01 h 11 m 50 s	Processor Version	0403

A180106_03

AS60A03_AS1W1B040320180106T165707_20180106T175136_0001.DBL

Date	2018-01-06	Instrument Mode	Adv. Low Altitude
Start Time	16:57:09 (61029)	Aircraft	BAS Twin Otter
Stop Time	17:51:37 (64297)	Retracker	OCOG
Distance	196.320 km	INS Resolution	50 Hz
Duration	00 h 54 m 29 s	Processor Version	0403

A180106_04

A560A04_AS1W1B040320180106175239_20180106181157_0001.DBL

Date	2018-01-06	Instrument Mode	Adv. Low Altitude
Start Time	17:52:41 (64361)	Aircraft	BAS Twin Otter
Stop Time	18:11:56 (65516)	Retracker	OCOG
Distance	70.830 km	INS Resolution	50 Hz
Duration	00 h 19 m 16 s	Processor Version	0403

A180109_00

A560A00_AS1W1B040320180109175151_20180109180506_0001.DBL

Date	2018-01-09	Instrument Mode	Adv. Low Altitude
Start Time	17:51:53 (64313)	Aircraft	BAS Twin Otter
Stop Time	18:05:07 (65107)	Retracker	OCOG
Distance	48.694 km	INS Resolution	50 Hz
Duration	00 h 13 m 15 s	Processor Version	0403

A180109_01

A560A01_AS1W1B040320180109183012_20180109193954_0001.DBL

Date	2018-01-09	Instrument Mode	Adv. Low Altitude
Start Time	18:30:14 (66614)	Aircraft	BAS Twin Otter
Stop Time	19:39:55 (70795)	Retracker	OCOG
Distance	272.042 km	INS Resolution	50 Hz
Duration	01 h 09 m 42 s	Processor Version	0403

A180109_02

A560A02_AS1W1B040320180109193958_20180109193958_0001.DBL

Date	2018-01-09	Instrument Mode	Adv. Low Altitude
Start Time	19:40:00 (70800)	Aircraft	BAS Twin Otter
Stop Time	20:41:53 (74513)	Retracker	OCOG
Distance	277.146 km	INS Resolution	50 Hz
Duration	01 h 01 m 53 s	Processor Version	0403

A180109_04

AS60A04_AS1WL1B040320180109T204202_20180109T204215_0001.DBL

Date	2018-01-09	Instrument Mode	Adv. Low Altitude
Start Time	20:42:04 (74524)	Aircraft	BAS Twin Otter
Stop Time	20:42:16 (74536)	Retracker	OCOG
Distance	0.990 km	INS Resolution	50 Hz
Duration	00 h 00 m 13 s	Processor Version	0403

A180109_05

AS60A05_AS1WL1B040320180109T204217_20180109T212239_0001.DBL

Date	2018-01-09	Instrument Mode	Adv. Low Altitude
Start Time	20:42:19 (74539)	Aircraft	BAS Twin Otter
Stop Time	21:22:40 (76960)	Retracker	OCOG
Distance	179.654 km	INS Resolution	50 Hz
Duration	00 h 40 m 22 s	Processor Version	0403

A180110_00

AS60A00_AS1WL1B040320180110T084301_20180110T095113_0001.DBL

Date	2018-01-10	Instrument Mode	Adv. Low Altitude
Start Time	08:43:03 (31383)	Aircraft	BAS Twin Otter
Stop Time	09:51:15 (35475)	Retracker	OCOG
Distance	270.574 km	INS Resolution	50 Hz
Duration	01 h 08 m 12 s	Processor Version	0403

A180110_01

AS60A01_AS1WL1B040320180110T095124_20180110T105058_0001.DBL

Date	2018-01-10	Instrument Mode	Adv. Low Altitude
Start Time	09:51:26 (35486)	Aircraft	BAS Twin Otter
Stop Time	10:50:59 (39059)	Retracker	OCOG
Distance	227.987 km	INS Resolution	50 Hz
Duration	00 h 59 m 34 s	Processor Version	0403

A180110_02

A560A02_AS1W1B040320180110T105103_20180110T111517_0001.DBL

Date	2018-01-10	Instrument Mode	Adv. Low Altitude
Start Time	10:51:05 (39065)	Aircraft	BAS Twin Otter
Stop Time	11:15:19 (40519)	Retracker	OCOG
Distance	84.613 km	INS Resolution	50 Hz
Duration	00 h 24 m 14 s	Processor Version	0403

A180110_03

A560A03_AS1W1B040320180110T111530_20180110T115254_0001.DBL

Date	2018-01-10	Instrument Mode	Adv. Low Altitude
Start Time	11:15:32 (40532)	Aircraft	BAS Twin Otter
Stop Time	11:52:56 (42776)	Retracker	OCOG
Distance	142.516 km	INS Resolution	50 Hz
Duration	00 h 37 m 24 s	Processor Version	0403

A180110_04

A560A04_AS1W1B040320180110T140949_20180110T151000_0001.DBL

Date	2018-01-10	Instrument Mode	Adv. Low Altitude
Start Time	14:09:51 (50991)	Aircraft	BAS Twin Otter
Stop Time	15:10:01 (54601)	Retracker	OCOG
Distance	237.267 km	INS Resolution	50 Hz
Duration	01 h 00 m 11 s	Processor Version	0403

A180110_05

A560A05_AS1W1B040320180110T151005_20180110T161511_0001.DBL

Date	2018-01-10	Instrument Mode	Adv. Low Altitude
Start Time	15:10:07 (54607)	Aircraft	BAS Twin Otter
Stop Time	16:15:13 (58513)	Retracker	OCOG
Distance	241.340 km	INS Resolution	50 Hz
Duration	01 h 05 m 06 s	Processor Version	0403

A180110_06

AS60A06_AS1W11B040320180110T161516_20180110T174521_0001.DBL

Date	2018-01-10	Instrument Mode	Adv. Low Altitude
Start Time	16:15:18 (58518)	Aircraft	BAS Twin Otter
Stop Time	17:45:23 (63923)	Retracker	OCOG
Distance	346.912 km	INS Resolution	50 Hz
Duration	01 h 30 m 05 s	Processor Version	0403

A180113_00

AS60A00_AS1W11B040320180113T124750_20180113T134739_0001.DBL

Date	2018-01-13	Instrument Mode	Adv. Low Altitude
Start Time	12:47:52 (46072)	Aircraft	BAS Twin Otter
Stop Time	13:47:40 (49660)	Retracker	OCOG
Distance	218.389 km	INS Resolution	50 Hz
Duration	00 h 59 m 49 s	Processor Version	0403

A180113_01

AS60A01_AS1W11B040320180113T134749_20180113T150247_0001.DBL

Date	2018-01-13	Instrument Mode	Adv. Low Altitude
Start Time	13:47:51 (49671)	Aircraft	BAS Twin Otter
Stop Time	15:02:48 (54168)	Retracker	OCOG
Distance	289.373 km	INS Resolution	50 Hz
Duration	01 h 14 m 58 s	Processor Version	0403

A180113_02

AS60A02_AS1W11B040320180113T150251_20180113T154235_0001.DBL

Date	2018-01-13	Instrument Mode	Adv. Low Altitude
Start Time	15:02:53 (54173)	Aircraft	BAS Twin Otter
Stop Time	15:42:36 (56556)	Retracker	OCOG
Distance	156.505 km	INS Resolution	50 Hz
Duration	00 h 39 m 44 s	Processor Version	0403

A180114_00

A560A00_ASIWL1B040320180114T115852_20180114T130815_0001.DBL

Date	2018-01-14	Instrument Mode	Adv. Low Altitude
Start Time	11:58:54 (43134)	Aircraft	BAS Twin Otter
Stop Time	13:08:16 (47296)	Retracker	OCOG
Distance	259.136 km	INS Resolution	50 Hz
Duration	01 h 09 m 23 s	Processor Version	0403

A180114_02

A560A02_ASIHL1B040320180114T232634_20180114T234051_0001.DBL

Date	2018-01-14	Instrument Mode	High Altitude
Start Time	23:26:36 (84396)	Aircraft	BAS Twin Otter
Stop Time	23:38:32 (85112)	Retracker	OCOG
Distance	52.775 km	INS Resolution	50 Hz
Duration	00 h 11 m 56 s	Processor Version	0403

A180115_00

A560A00_ASIWL1B040320180115T000811_20180115T005935_0001.DBL

Date	2018-01-15	Instrument Mode	Adv. Low Altitude
Start Time	00:08:13 (00493)	Aircraft	BAS Twin Otter
Stop Time	00:59:36 (03576)	Retracker	OCOG
Distance	194.479 km	INS Resolution	50 Hz
Duration	00 h 51 m 23 s	Processor Version	0403

A180115_01

A560A01_ASIHL1B040320180115T010651_20180115T013457_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	01:06:53 (04013)	Aircraft	BAS Twin Otter
Stop Time	01:37:44 (05864)	Retracker	OCOG
Distance	120.318 km	INS Resolution	50 Hz
Duration	00 h 30 m 51 s	Processor Version	0403

A180115_02

AS60A02_ASHL1B040320180115T013925_20180115T014046_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	01:39:27 (05967)	Aircraft	BAS Twin Otter
Stop Time	01:40:45 (06045)	Retracker	OCOG
Distance	4.974 km	INS Resolution	50 Hz
Duration	00 h 01 m 19 s	Processor Version	0403

A180115_03

AS60A03_ASHL1B040320180115T014048_20180115T014937_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	01:40:50 (06050)	Aircraft	BAS Twin Otter
Stop Time	01:49:38 (06578)	Retracker	OCOG
Distance	34.343 km	INS Resolution	50 Hz
Duration	00 h 08 m 49 s	Processor Version	0403

A180115_04

AS60A04_ASHL1B040320180115T014940_20180115T022019_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	01:49:42 (06582)	Aircraft	BAS Twin Otter
Stop Time	02:20:20 (08420)	Retracker	OCOG
Distance	119.020 km	INS Resolution	50 Hz
Duration	00 h 30 m 38 s	Processor Version	0403

A180115_05

AS60A05_ASHL1B040320180115T022800_20180115T023136_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	02:28:02 (08882)	Aircraft	BAS Twin Otter
Stop Time	02:31:37 (09097)	Retracker	OCOG
Distance	15.457 km	INS Resolution	50 Hz
Duration	00 h 03 m 36 s	Processor Version	0403

A180115_06

AS60A06_ASIHL1B040320180115T023403_20180115T023903_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	02:34:05 (09245)	Aircraft	BAS Twin Otter
Stop Time	02:39:04 (09544)	Retracker	OCOG
Distance	21.369 km	INS Resolution	50 Hz
Duration	00 h 04 m 60 s	Processor Version	0403

A180115_07

AS60A07_ASIHL1B040320180115T023911_20180115T024051_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	02:39:13 (09553)	Aircraft	BAS Twin Otter
Stop Time	02:40:53 (09653)	Retracker	OCOG
Distance	7.152 km	INS Resolution	50 Hz
Duration	00 h 01 m 40 s	Processor Version	0403

A180115_08

AS60A08_ASIHL1B040320180115T024422_20180115T024659_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	02:44:24 (09864)	Aircraft	BAS Twin Otter
Stop Time	02:47:01 (10021)	Retracker	OCOG
Distance	10.977 km	INS Resolution	50 Hz
Duration	00 h 02 m 37 s	Processor Version	0403

A180115_09

AS60A09_ASIHL1B040320180115T030556_20180115T030747_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	03:05:58 (11158)	Aircraft	BAS Twin Otter
Stop Time	03:07:48 (11268)	Retracker	OCOG
Distance	7.861 km	INS Resolution	50 Hz
Duration	00 h 01 m 50 s	Processor Version	0403

A180115_10

AS60A10_ASHL1B040320180115T031755_20180115T032022_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	03:17:57 (11877)	Aircraft	BAS Twin Otter
Stop Time	03:20:23 (12023)	Retracker	OCOG
Distance	10.406 km	INS Resolution	50 Hz
Duration	00 h 02 m 26 s	Processor Version	0403

A180115_11

AS60A11_ASHL1B040320180115T032202_20180115T032352_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	03:22:04 (12124)	Aircraft	BAS Twin Otter
Stop Time	03:23:53 (12233)	Retracker	OCOG
Distance	7.701 km	INS Resolution	50 Hz
Duration	00 h 01 m 49 s	Processor Version	0403

A180115_12

AS60A12_ASHL1B040320180115T032918_20180115T032940_0001.DBL

Date	2018-01-15	Instrument Mode	High Altitude
Start Time	03:29:20 (12560)	Aircraft	BAS Twin Otter
Stop Time	03:29:41 (12581)	Retracker	OCOG
Distance	1.445 km	INS Resolution	50 Hz
Duration	00 h 00 m 21 s	Processor Version	0403

A180115_13

AS60A13_ASHL1B040320180115T181255_20180115T185843_0001.DBL

Date	2018-01-15	Instrument Mode	Adv. Low Altitude
Start Time	18:12:57 (65577)	Aircraft	BAS Twin Otter
Stop Time	18:58:44 (68324)	Retracker	OCOG
Distance	167.107 km	INS Resolution	50 Hz
Duration	00 h 45 m 48 s	Processor Version	0403

22APPENDIX KAREN processing report

KAREN Altimeter

Processing chain and file format

Reference Code : MS-DTU-KAR-03- PFF-033
Issue : 3.3
Date : 6^h May 2020

MetaSensing BV
Huygensstraat 44
2201DK Noordwijk, The Netherlands
Tel.: +31 71 751 5960
Email: info@metasensing.com

Document Status Log

Issue	Change description	Date
1.0	First version	13 Aug 2018
1.1	Additional sections included	20 Aug 2018
1.2	Editing correction and formatting	22 Aug 2018
2.0	Approval	29 Aug 2018
2.1	Implemented comments from DTU	25 Oct 2018
2.2	Implemented comments from ESA	5 Nov 2018
2.3	Implemented additional comments from ESA	12 Dec 2018
3.0	Approval	14 Dec 2018
3.1	Minor correction and approval	10 Jan 2019
3.2	Added the <i>.levc</i> description in Table 2	4 July 2019
3.3	Upgraded Table 2	6 May 2020

Table of contents

1	Introduction.....	4
2	Backprojection algorithm.....	7
3	Processing chain.....	8
3.1	Raw-data unpacking.....	9
3.2	Range Compression	10
3.3	Zero-Doppler Filtering.....	11
3.4	Navigation data post-processing	12
3.5	GBP Focusing	12
3.5.1	Run-time performance	14
3.6	Multilooking	15
3.7	NetCDF Encapsulation	17
4	NetCDF File Content	18
4.1	File Name.....	18
4.2	Variables	20

1 Introduction

MetaSensing is a Dutch/Italian company offering radar sensors and services [Ref. 1]. MetaSensing's radar products cover a wide range of applications as mapping, deformation monitoring, weather monitoring, coastal surveillance and harbor management. During the past few years the MetaSensing Ka-band radar altimeter, KAREN, has been deployed in the framework of the ESA's CryoVEx validation and monitoring activities for sea ice and land ice. In particular, three airborne campaigns have been performed with KAREN in October 2016 (EGIG line, Greenland), Spring 2017 (Arctic) and Winter 2017/2018 (Antarctic).

The KAREN system is an interferometric frequency modulated continuous wave (FMCW) SAR altimeter working at the Ka frequency band. A block scheme of the radar instrument is shown in Figure 1. A baseband signal is up-shifted to the Ku band before being frequency-doubled to 34.5 GHz. The transmitting antenna continuously radiates linear chirps centered at this frequency, eventually amplified by the High Power Amplifier (HPA); the echoes scattered by the monitored scenario are received by two separate receiving antennas. The system works according to a deramping principle: a replica of the transmitted signal is mixed with the received signal which has been amplified by a Low Noise Amplifier (LNA). The Intermediate Frequency deramped signal (beat frequency) is sampled and stored as raw data, without any range windowing applied.

Figure 1: Block diagram of the KAREN system, the Ka band radar altimeter by MetaSensing.

The KAREN system is controlled by the user friendly MetaSAR GUI, see Figure 2. By that it is possible to configure the system parameters, to start and stop each acquisition and to monitor if eventual alerts or error messages occur.

Figure 2: Configuration window of the MetaSAR AirGUI, the software tool to control the MetaSensing airborne radar sensors.

In particular on the right part of the GUI a configuration tab is selected, in which the main configuration parameters can be set.

Central frequency (F_c) Ideally, it can be tuned; however, it has been kept fixed to the value of 34.5 GHz during any KAREN campaign, as the one providing maximum transmitted bandwidth possible. The value of this parameter is provided within the delivered NetCFD file.

Bandwidth (B_w) 0-600 MHz. where 0 corresponds to a single tone transmission at the central frequency, any other specified transmitted bandwidth is centered at the central frequency. When possible, it has been kept to its maximum value of 600MHz, in order to maximize the slant range resolution to 25 cm (value shown in the GUI as a direct consequence of the set bandwidth). Sometimes, especially when high altitude acquisitions were performed, the bandwidth needs to be reduced to lower values, in order to increase the maximum operational range of the radar (in FMCW

systems the maximum range is inversely proportional to the transmitted bandwidth). The value of this parameter is provided within each delivered NetCFD file.

Pulse Repetition Frequency (PRF) The repetition rate of the linearly frequency modulated chirps can vary between 0.5 and 25 KHz (list of discrete values). This parameter should be traded off between maximum operation range and Doppler ambiguities. The value of this parameter is provided within each delivered NetCFD file.

Sampling frequency (F_s) The sampling frequency can be selected by GUI to be 10 MHz, 25 MHz or 50 MHz. However, the pre-sampling Nyquist filters should be manually changed according to the chosen F_s value, which is not a trivial operation during flights. Therefore, the sampling frequency has been selected to 25MHz and kept as such for all KAREN campaigns.

Once set, the values of these parameters are stored in the header of the performed acquisition files. Most of them have been included in the list of parameters within the delivered NetCDF files, see chapter 4.

As reference, a typical acquisition during the KAREN campaigns in Low Altitude Mode (LAM, the terrain is expected ~300 meters below the aircraft) is performed with the following parameters: $F_c = 34.5$ GHz, $B_w = 600$ MHz, $F_s = 25$ MHz, $PRF = 6.15$ KHz, to which corresponds a maximum operational range of 508 meters and an unambiguous Doppler bandwidth wide enough at the considered aircraft speed and antenna beamwidth.

The remaining of this document describes the steps implemented in the processing of data acquired by the KAREN system aiming at delivering level-1b data, i.e. focused multilooked data. Besides this introductory chapter, a short overview of the ground-backprojection (GBP) algorithm is given in chapter 2, while the processing chain is documented step by step in chapter 3; finally, chapter 4 describes the data format of delivered files.

2 Backprojection algorithm

The processor for the KAREN altimeter data is based on a time-domain ground-backprojection (GBP) method ([Ref. 2]). Opposite to the frequency-domain approach, separate motion compensation and range migration correction steps are not required because the GBP algorithm handles non-ideal motion/sampling implicitly and can precisely perform beam-steering [Ref. 6]. Therefore, the GBP algorithm can be used for any imaging geometry. This gives flexibility to use the same algorithm core to process data acquired at diverse configurations (side-looking, nadir-looking, bistatic), trajectories or modes.

The GBP algorithm interpolates and phase-compensates each received echo at the desired positions to be focused. Because the radar echo has been sampled according to the Nyquist criterion, it can be interpolated with arbitrary accuracy at any illuminated image position. By coherently adding the contributions of each echo to each desired position, the focusing is performed. The contribution of each echo is computed according to the acquisition geometry.

The drawback of time-domain GBP is that it is more computationally expensive than the frequency domain methods, because the geometry of each echo is taken into consideration. However, because technology is constantly increasing the speed and the ability to perform parallel computations (GBP is highly parallelizable), the computational expense of GBP is becoming less and less a concern if compared to its inherent advantages over frequency-domain approaches [Ref. 7]. GBP offers several opportunities for seamless parallelisation based in NVIDIA graphic cards. In Figure 3 it is shown a computer at MetaSensing laboratory busy processing KAREN data with eight graphic processing units (GPU) of last generation visible on top of the machine.

Figure 3: Example of processing machine at MS labs with 8 GPUs.

3 Processing chain

The MetaSAR Processor is the tool by MetaSensing to elaborate SAR images from the collected raw data. It is a generic software which can be used for any radar system by MetaSensing to generate both strip images (typical of side looking SAR instruments) and altitude profiles (typical of altimeters, as the ones discussed in this document). Figure 4 shows the block diagram implemented by the processor for the KAREN data, with fundamental steps leading from collected Level-0 data to the delivered Level-1B data. Each step is described in the following sub-sections.

Figure 4: Block diagram for the KAREN processor.

3.1 Raw-data unpacking

Figure 5 shows the contents of a typical acquisition file from the KAREN altimeter. The deramped radar data for both channels are stored in fixed-dimensions *.msr* files, whose number depends on the length (in time) of the acquisition. These are joined together during the ingestion phase. Together with radar data, the corresponding configuration file (*.msmpl*) and time synchronization file (*.msmtl*) are provided. A real-time navigation file (*.gps*) is also associated to each acquisition. The GPS file contains both real time navigation information and GPS raw data which can be used during post processing in order to improve the accuracy of the navigation data.

20170321121804.gps	14,139 KB	GPS File
20170321121804.msmpl	557 KB	MSMPL File
20170321121804.msmtl	343 KB	MSMTL File
20170321121804_1.msr	20,001 KB	MSR File
20170321121804_2.msr	20,001 KB	MSR File
20170321121804_3.msr	20,001 KB	MSR File
20170321121804_4.msr	20,001 KB	MSR File
20170321121804_5.msr	20,001 KB	MSR File
20170321121804_6.msr	20,001 KB	MSR File
20170321121804_7.msr	20,001 KB	MSR File
20170321121804_8.msr	20,001 KB	MSR File

Figure 5: Example of the contents of a KAREN acquisition file.

The KAREN instrument data extraction is organized in two steps:

- Header extraction.
- Level-0 data extraction.

Using the information included in the header, i.e. instrument configuration and user settings such as used Pulse Repetition Frequency (PRF), Sampling Frequency (F_s), etc, the time-tagged observation data is arranged in a raw-data matrix, one for each receiving channel: rows represent slow time domain, which parametrizes the along track position of the platform (sampled at PRF), while columns represent the fast time domain, which parametrizes the beat frequency (sampled at F_s).

3.2 Range Compression

Raw data of each channel (deramped frequency-modulated continuous waveforms) are the input for this step. The range compression is implemented as a simple Fast Fourier Transform (FFT) in range. Furthermore, a Hann window is applied to trade-off side-lobes level and resolution.

Figure 6 shows an example of Range-Doppler map for the KAREN range compressed data, which have been acquired at an altitude of ~ 365 m AGL during March 19th, 2017, for one of the two receiving channels.

Figure 6: Example of processed Range-Doppler map. The colormap is expressed in dB.

To reduce the processing effort during further steps, the range compressed output is analyzed in the Range-Time domain to roughly estimate the range-delay of the signal and to determine the minimum and maximum slant range limits to the grid used for the backprojection beam steering.

3.3 Zero-Doppler Filtering

The main interest of altimeter data lies in the echoes coming from the nadir direction of the aircraft during its motion. Therefore, the range compressed data are filtered around the Zero Doppler in the Doppler dimension with a Doppler bandwidth corresponding to half the used PRF. Eventual folding effects at the extremities of the Doppler spectrum are avoided in this way. This is shown in Figure 7. By filtering half of the bandwidth, it is possible focusing the data with 100 looks and 5 m resolution along track.

Figure 7: Zero-Doppler filtering (black rectangle) by half of the spectrum width, corresponding to $PRF/2$.

3.4 Navigation data post-processing

The KAREN system is equipped with a dedicated navigation unit, a compact, single enclosure GNSS+INS receiver. The accuracy of the real-time solution computed by the unit can be improved by post-processing. This is usually done in the KAREN processing flow.

However, to have consistency with other on-board remote sensing instruments (ASIRAS Ku-band altimetry, Airborne Laser Scanner, etc) during the campaigns, it has been agreed with final users to adopt a common navigation solution for all provided datasets. The navigation units deployed by DTU is the most accurate one among the on-board units during the KAREN acquisitions. Different models have been used in different campaigns, so the reader is invited to refer to dedicated campaign reports. An importing step has been implemented in the KAREN processing to properly convert the DTU navigation data into an acceptable format to the KAREN processor. The same navigation data is provided in the delivered NetCDF files.

3.5 GBP Focusing

As introduced in chapter 2, the backprojection algorithm implements the beam steering for the Doppler-filtered range compressed data for each sample on any arbitrary surface grid. The geometry of the output grid can be set to follow any direction: for example, the processed data can be directly projected on the Universal Transverse Mercator (UTM) system. The post-processed navigation information is used to determine the vectors joining the position of the beam center and the position of the point-target in the grid. With the knowledge of the ranges and angles relative to each point-target the vectors are phase compensated and then coherently summed up to form the focused beam. This is repeated for each point-target of the grid. As a result, a 2D image is obtained, as the one shown in Figure 10, characterized by a resolution of 0.05 m X 0.2 m (along track X nadir).

The main features of the backprojection algorithm are described in detail in the following:

- 1) The target function in the spatial domain $f[i, j]$ is created with the same dimensions of the reconstruction grid (output matrix).
- 2) The Nadir Coordinate System (NCS) T_{xyz} is defined for each output pixel. The NCS is aligned with the x-axis pointing in the direction of the aircraft forward motion, the z-axis pointing downward to the centre of the earth, and the y-axis pointing to the right direction to form an orthogonal right-handed system, as shown in Figure 8

Figure 8: Nadir Coordinate System. Note, in this figure the aircraft is supposed flying with some yaw angle: the aircraft velocity vector is not parallel to the aircraft longitudinal direction.

3) The slant-range values $r(u, i, j)$ to the target are calculated for each pixel point $[i, j]$ on the output grid (NCS) and for each antenna position $P(u)$ on the synthetic aperture:

$$r(u, i, j) = \sqrt{(T_x - P_x(u))^2 + (T_y - P_y(u))^2 + (T_z - P_z(u))^2}$$

Note, as mentioned in chapter 2, the range cell migration and the motion compensation steps are implicitly performed in the backprojection, as the actual antenna positions are accounted for each pixel in the determination of the slant range to the target.

4) A coherent summation is performed by iteratively using the following formula along the synthetic aperture:

$$f[i, j] = f[i, j] + S_D[u] e^{j \frac{4\pi}{\lambda} [r(u, i, j) - r_{ref}(i, j)]}$$

where S_D refers to the range compressed data. In this way, the portion of each range compressed pulse that corresponds to the range to a given pixel from each aperture position is multiplied by the expected phase for that range and it is summed up across the entire collection.

It is worth to underline that no Fourier transform is involved in the GBP focusing: for every single pixel in the raw data the above coherent summation is performed to integrate the pulses in the slow-time domain. The number of integrated pulses for each pixel depends on the length of the synthetic aperture and it is computed based on the desired resolution and on the actual trajectory.

3.5.1 Run-time performance

As mentioned in chapter 2, KAREN data is processed by using multiple video cards in a single computer. The parallel computing is now implemented on the only focusing step. As a reference, Table 1 shows the overall run-time performance to process 1 minute of acquisitions by KAREN, represented by 6 GB of raw data (2 interferometric channels, 25MHz sampling frequency, 2 bytes per sample). The mentioned GPU's are Geforce GTX 1080 model by Asus.

Table 1 - Run-time performance to process 1 minute of KAREN raw data (6GB, given by two interferometric channels sampled at 25 MHz and stored with 2 bytes)				
Nr. of GPUs	Range Compression	Doppler Filtering	GBP Focusing	Total
1	4 min	27 min	40 min	72 min
6			7 min	38 min

One of the current developments undergoing at MetaSensing is the implementation of parallel processing also in the Doppler Filtering step, to further improve the overall run-time performance. Additionally, an adaptative range gating filter is being designed, so that only the actual range bins with meaningful data will be processed along the nadir direction, rather than the entire range profiles.

3.6 Multilooking

To reduce the inherent speckle noise of radar images, either spatial filtering or multi-look processing can be applied, both at the expense of spatial resolution ([Ref. 3], [Ref. 4]). The KAREN processor implements the multi-look method. Figure 9 shows the principle. The radar beam is divided into several sub-beams (three in the figure), each one providing an independent “look” at the illuminated scene. The final output image is obtained by summing and averaging together the output of each look, in which the amount of speckle is reduced.

Figure 9: Principle of multi-look processing [Ref. 5].

The KAREN processor implements the multilooking by applying a FFT in the Doppler dimension to the back-projected data and dividing the spectrum in the desired number of looks. Hamming windowing is performed in the along-track direction and an IFFT is applied to each look to restore the backprojected data domain.

In the delivered Level-1b data, the power (*pwr*), the phase (*pha*) and coherence (*coh*) are computed according to:

$$pwr(rg) = \frac{1}{L} \sum_{l=1}^L \left(\frac{|S(l, rg, 1)|^2 + |S(l, rg, 2)|^2}{2} \right)$$

$$X(rg) = \frac{1}{L} \sum_{l=1}^L \left(\frac{S(l, rg, 1) \cdot conj(S(l, rg, 2))}{\sqrt{|S(l, rg, 1)|^2 \cdot |S(l, rg, 2)|^2}} \right)$$

$$pha(rg) = \arg(X(rg))$$

$$coh(rg) = \text{abs}(X(rg))$$

Where $S(l, rg, 1)$ and $S(l, rg, 2)$ refer to the back-projected data for look number l at range rg of channel 1 and channel 2, respectively, where L represents the total number of looks.

As mentioned, a loss of resolution is obtained within this step. Typically, the backprojected data (SLC) have a grid spacing and resolution of 0.05 m, while the delivered multilooked data have 5 m resolution and 100 looks.

3.7 NetCDF Encapsulation

The final step of the KAREN processing chain is represented by the NetCDF encapsulation of the processed data and of all the relevant ancillary data such as time tags, geographical position, and other radar/processing parameters. The required fields to be included have been agreed with final users.

During this step the transformation from NCS to geographical coordinate system is also performed. Additionally, the time reference grid is converted from the GPS time to UTC (Universe Time Coordinates) in seconds since the midnight of the 1st of January 2000.

Figure 3 shows an example of a delivered KAREN waveforms plotted in terms of range-delay versus time acquired on the 31st of March 2017, beginning at 15:32:53 (GPS time). For convenience, the time axes is shown in time since the beginning of acquisition.

Figure 10: Example of KAREN Range-delay versus time dataset provided in the delivered NetCDF files.
The colormap is expressed in dB.

4 NetCDF File Content

KAREN data are provided in NetCDF format (*.nc* extension). Each NetCDF file contains:

- Focused multilooked altimeter waveforms
- Multilooked phase differences between the two channels
- Coherence between the two channels
- Waveform position
- Sensor attitude data
- Radar and processing parameters.

The NetCDF files are three dimensional, with *Range* (size 247), *Time* (4767) and *space_3d* (3). The *range* and *time* dimensions are related to the pre-defined grid in which the focused SAR pixels are projected. This grid is regular in space.

The *Range* dimension refers to the range delays to the pixels, in nadir direction, equally spaced.

The *Time* dimension refers to the UTC time since the midnight of the 1st of January 2000, during which the pixel data have been acquired, equally spaced.

The *space_3d* dimension is used to write the three-dimensional position and velocity vector coordinates of the sensor.

The file name format and the detailed contents of the NetCDF files are explained in the following paragraphs.

4.1 File Name

The delivered NetCDF files are named according to a defined structure, as in the following example:

KAR_OPER_Level1b_20170331T104652_20170331T105245_hamh.nc

KAR_OPER: Indicates that that data have been acquired by the KAREN system in its full operational mode.

Level1b: Processing level, i.e. focused multilooked SAR data.

20170331T104652: Date and time of the start of acquisition, in the format YYYYMMDDTHHMMSS, where YYYY is the year, MM the month, DD the day, *T* is a separator character indicating Time, HH is the hour, MM the minutes and SS the seconds, in UTC time.

20170331T105245: Date and time of the end of acquisition in the format YYYYMMDDTHHMMSS where YYYY is the year, MM the month, DD the day, *T* is a separator character indicating time, HH the hour, MM the minutes and SS the seconds, in UTC time.

hamh: Additional info. The last four digits before the *.nc* file extension are used to differentiate the various dataset KAREN datasets versions which have been delivered. In Table 2 an overview is given about the different versions, including a short description of the kind of processing which has been differently done with respect to previous version. It is advised to use the most recent one.

Table 2 – Versions of KAREN datasets		
Version	Info	Delivery date (KAREN dataset)
*_vvvv	First version processed with Hann window.	Jun 2018 (Spring 2017)
*_hamh	Changed the Hann by the Hamming window ($\alpha=0.54$)	Aug 2018 (Fall 2016, spring 2017)
*_leva	The RF antenna position has been corrected, measured lever arms have been introduced w.r.t. IMU reference point	Nov 2018 (Fall 2016, Spring 2017 and Antarctica 2018)
*_levb	A bug in the processing has been corrected, which was causing sudden jumps in longitude values in the <i>_leva</i> version	Dec 2018 (Fall 2016, Spring 2017 and Antarctica 2018)
*_levc	Doppler filtering improvement preventing high sidelobes contribution in the slant-range direction	Few samples delivered in June 2019 for assessment of users. After approval, all KAREN datasets from any mission have been re-processed and delivered in this format.

4.2 Variables

range

Size: 247x1

Dimensions: range

Datatype: double

Attributes: long_name = range-delay in nadir direction. The difference between the samples of the range variable gives the range spacing.

units = '[m]'

time_ka

Size: 4767x1

Dimensions: time

Datatype: double

Attributes: long_name = Time to the instant the L1B waveform touches the surface. Time in UTC representing the seconds since the midnight of the 1st of January 2000. The difference between the samples of the time_ka variable gives the time spacing.

units = '[s]'

com_altitude_ka

Size: 4767x1

Dimensions: time

Datatype: double

Attributes: long_name = Altitude of the aircraft navigation unit above the reference ellipsoid (WGS84)

units = '[m]'

com_altitude_rate_ka

Size: 4767x1

Dimensions: time

Datatype: double

Attributes: long_name = Instantaneous altitude rate at aircraft navigation unit with respect to the reference ellipsoid (WGS84)

units = '[m/s]'

com_position_vector_ka

Size: 3x4767
Dimensions: space_3d, time
Datatype: double
Attributes: long_name = Position vector (x, y, z) at the aircraft navigation unit
units = '[m]'

com_velocity_vector_ka

Size: 3x4767
Dimensions: space_3d,time
Datatype: double
Attributes: long_name = Velocity vector (x, y, z) at the aircraft navigation unit
units = '[m/s]'

hr_power_waveform_ka

Size: 247x4767
Dimensions: range,time
Datatype: double
Attributes: long_name = 'level-1B multi-looked power waveform'(2 channels)
units = '[]'

latitude_ka

Size: 4767x1
Dimensions: time
Datatype: double
Attributes: long_name = 'Latitude of measurement [-90, +90]: Positive at North, Negative at South'
units = '[deg]'

longitude_ka

Size: 4767x1
Dimensions: time
Datatype: double
Attributes: long_name = 'Longitude of measurement [0, 360]'
units = '[deg]'

off_nadir_pitch_angle_pf_ka

Size: 4767x1
Dimensions: time
Datatype: double
Attributes: long_name = 'Pitch angle with respect to the nadir pointing direction'
units = '[deg]'

Off_nadir_roll_angle_ka

Size: 4767x1
Dimensions: time
Datatype: double
Attributes: long_name = 'Roll angle with respect to the nadir pointing direction'
units = '[deg]'

Off_nadir_yaw_angle_pf_ka

Size: 4767x1
Dimensions: time
Datatype: double
Attributes: long_name = 'Yaw angle with respect to the forward velocity vector'
units = '[deg]'

Heading_angle_ka

Size: 4767x1
Dimensions: time
Datatype: double
Attributes: long_name = 'Heading angle with respect to the true North'
units = '[deg]'

hr_coh_waveform_ka

Size: 247x4767
Dimensions: range,time
Datatype: double
Attributes: long_name = 'Waveform coherence between the 2 channels'
units = '[]'

hr_phase_waveform_ka

Size: 247x4767

Dimensions: range,time
Datatype: double
Attributes:
long_name = 'Waveform phase between the 2 channels'
units = '[]'

TxBw

Size: 1x1
Dimensions:
Datatype: double
Attributes:
long_name = 'Transmitted Bandwidth'
units = 'hertz [Hz]'

Fc

Size: 1x1
Dimensions:
Datatype: double
Attributes:
long_name = 'Central Frequency'
units = 'hertz [Hz]'

PRF

Size: 1x1
Dimensions:
Datatype: double
Attributes:
long_name = 'Pulse Repetition Frequency'
units = 'hertz [Hz]'

AzBw

Size: 1x1
Dimensions:
Datatype: double
Attributes:
long_name = 'Azimuth bandwidth prior to multilooking'

units = '[Hz]'

MeanForwardVelocity

Size: 1x1

Dimensions:

Datatype: single

Attributes:

long_name = 'Velocity in the flight direction'

units = '[m/s]'

Looks

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'Number of looks'

units = '[]'

BaselineHor

Size: 1x1

Dimensions:

Datatype: single

Attributes:

long_name = 'Horizontal baseline (half of the physical baseline length)'

units = 'units [cm]'

BaselineVer

Size: 1x1

Dimensions:

Datatype: single

Attributes:

long_name = 'Vertical baseline (half of the physical baseline length)'

units = 'units [cm]'

StartYearUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Year of the Start of Acquisition'
units = '[year]'

StartMonthUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Month of the Start of Acquisition'
units = '[month]'

StartDayUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Day of the Start of Acquisition'
units = '[day]'

StartHourUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Hour of the Start of Acquisition'
units = '[hour]'

StartMinUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Minutes of the Start of Acquisition'

units = '[min]'

StartSecUTC

Size: 1x1

Dimensions:

Datatype: single

Attributes:

long_name = 'UTC Seconds of the Start of Acquisition'

units = '[sec]'

FinalYearUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Year of End of Acquisition'

units = '[year]'

FinalMonthUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Month of End of Acquisition'

units = '[month]'

FinalDayUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Day of End of Acquisition'

units = '[day]'

FinalHourUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Hour of End of Acquisition'
units = '[hour]'

FinalMinUTC

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'UTC Minutes of End of Acquisition'
units = '[min]'

FinalSecUTC

Size: 1x1

Dimensions:

Datatype: single

Attributes:

long_name = 'UTC Seconds of End of Acquisition'
units = '[sec]'

Dummy

Size: 1x1

Dimensions:

Datatype: int32

Attributes:

long_name = 'Dummy value'
units = '[]'

References

- [Ref. 1] <https://www.metasensing-group.com/>
- [Ref. 2] L.M. H.Ulander, H. Hellsten, and G.Stenström, "Synthetic-aperture radar processing using fast factorized back-projection," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 39, pp. 760–776, Jul. 2003.
- [Ref. 3] J. M. Durand. et al., "Speckle in SAR images: An evaluation of filtering techniques," *Adv. Space Res.*, vol. 7, no. 11, pp. 301-304, 1987.
- [Ref. 4] F. K. Li, C. Croft, and D. N. Held, "Comparison of several techniques to obtain multiple-look SAR imagery," *IEEE Trans. Geosci. Remote Sensing*, vol. GE-21. July 1983.
- [Ref. 5] F. Sarti, Remote sensing and SAR images processing characterization and speckle filtering in radar images, ESA radar remote sensing course, Tartu, Estonia, 16-20 April 2012
On line: https://earth.esa.int/c/document_library/get_file?folderId=226458&name=DLFE-2125.pdf
- [Ref. 6] A. Egidio and W. H. F. Smith, "Fully Focused SAR Altimetry: Theory and Applications," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 55, no. 1, pp. 392-406, Jan. 2017.
doi: 10.1109/TGRS.2016.2607122
- [Ref. 7] Doerry, A.W., Bishop, E.E. Miller, J.A., "Basics of backprojections algorithm for processing SAR images", Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550, Feb 2016.