Deliverable 1.1: DAS field dataset to compare technologies and deployment scenarios – Antarctica Dataset

DigiMon

Digital monitoring of CO_2 storage projects

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DigiMon Deliverable D.1.1 Version 1,

September 2020

Revision

Version	Date	Change	Page
1.0	15.09.2020	First version	All

Document distribution

ACT Coordinator

- Research Council of Norway

ACT national funding agencies

- Forschungszentrum Jülich GmbH, Projektträger Jülich, (FZJ/PtJ), Germany.
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1 Introduction

This report describes a Distributed Acoustic Sensing (DAS) dataset acquired by the British Antarctic Survey (BAS) and the University of Oxford in Antarctic during 2020. The field dataset contributes to the Deliverable D1.1 of the DigiMon project (DAS field dataset to compare technologies and deployment scenarios), which is associated with tasks 1.2 and 1.3 of the project.

The use of fibre and DAS for seismic monitoring is a recently developed technology with enormous potential, and, until recently, never tested in Antarctica. This dataset allows us to investigate how well DAS methods can be used to record icequakes and to interrogate the internal properties of ice. In the Austral Summer of 2020, fibre-optic cables were used to study the Rutford Ice Stream and the Skytrain Ice Rise. This research complemented already planned fieldwork at Rutford, as part of the NERC-funded BEAMISH project (https://www.bas.ac.uk/project/basal-conditions-on-rutford-ice-stream/). Prof Kendall's involvement was funded through the NERC Collaborative Antarctic Science Scheme (CASS). Scientists from BAS (British Antarctic Survey - https://www.bas.ac.uk) and Oxford worked collaboratively with Silixa Limited, who provided the fibre optic cable and interrogator used to acquire the data.

Plate 1: Rutford Ice Stream survey area

Surveys were acquired at two different locations within Antarctica: the Rutford Ice Stream and Skytrain Ice Rise. At Rutford surface deployments of fibre were used to monitor icequakes and image the velocity structure of the firn layer, while the internal ice sheet structure was imaged at Skytrain using borehole installed cables.

Ice streams are the principle regulators of ice sheet volumes, but our knowledge of controls on their dynamical behaviour is still incomplete. Geophysical methods provide our best means of imaging the internal structure of ice streams and considerable advances have been made in recent years using seismic and radar methods. The Rutford Ice Stream is part of the West Antarctic Ice Sheet and covers some of the most dramatic topography on Earth. The base of the ice is up to 7 km below the top of the Ellsworth mountains that flank the western edge of the ice stream. Rutford flows at around 400m per year. Its dynamics are controlled by many factors including the topography and hydrological system at the base of the ice, but also external factors such as tides. Rutford is notable for an abundance of icequakes.

Ice rises are large grounded areas of ice surrounded by floating ice shelves. They play a key role in ice sheet stability, and their internal structure records a history of ice-flow, including periods of being unpinned due to ice sheet melting. As such, they provide important records of how ice sheets respond to global warming. The Skytrain Ice Rise lies near the Heritage Range, one the Ronne Ice Sheet.

2 Description of datasets

2.1 Pre-Survey Trials

Prior to commencing field deployments, both the interrogator and fibre-optic cable to be deployed at Rutford were tested at the Rothera field research centre (Figure 1). All equipment was in working order and a summary of acquisition details is included in Table 1.

Figure 1 *– Testing the cable and interrogator in the laboratory at Rothera Field Station.*

Table 1: *Details of pre-survey test.*

Survey name	Start date* /file	End date /file	iDAS used	Comments
RotheraTest	7.1.	7.1	14029 (black)	Saved on: - HD-IDAS3: IDAS14029-black/ RotheraTest test files recorded in Rothera with the cable still on the drum

2.2 Rutford Ice Stream

2.2.1 Survey Configuration

Three different array geometries using 1km of fibre-optic cable were install between 11th and 21st January 2020 along two different orientations. Line 1 was positioned perpendicular to the flow of the ice stream, with both a linear and triangular geometry deployed. Line 2 was position in the direction of the ice stream flow, and along this line a linear and 'hockey stick' configuration was installed. To compliment the survey, three conventional 3-C geophones were also deployed along Line 1 (Figure 2). Coordinates have been measured on 20th January 2020 with differential GPS, however these are still to be processed and the two coordinates in Figure 2 have been measured with handhold GPS on 21st January 2020.

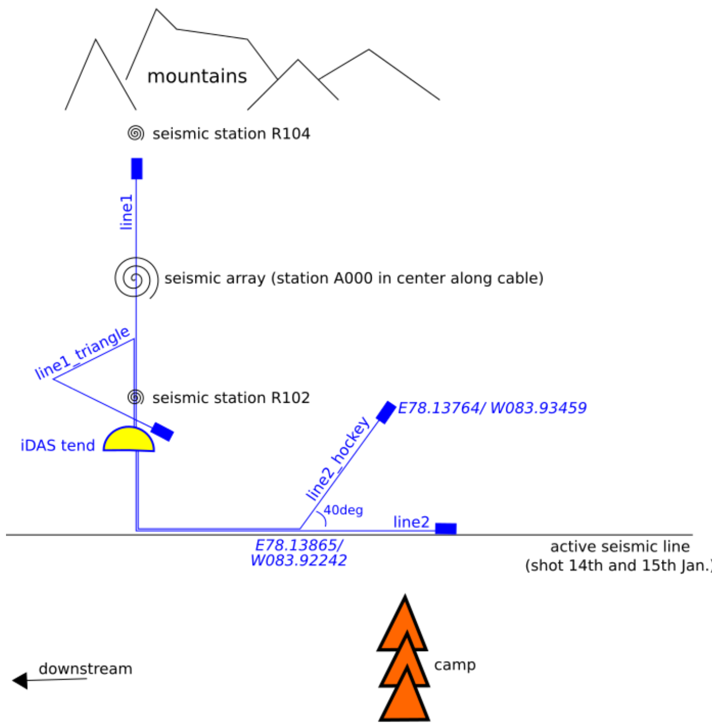


Figure 2: *the field setup at Rutford Ice Stream, indicating the three line configurations: linear (lines 1 and 2); hockey stick; triangle. The recording tent is indicated in yellow. The location of three conventional three-component geophones with a Reftek recorder are marked A000, R102 and R104. The camp (red triangles) was roughly 3 km from the cable. Downstream refers to the flow of the Rutford Ice Stream.*

Both passive and active (refraction and reflection) seismic data were recorded during each cable configuration, and images from these surveys are these are shown in Figure 3. Individuals surveys and recorded file names are detailed in Table 2, while field notes relating to these surveys are included in Appendix B.

Figure 3: *Field deployment photo at Rutford Ice Stream (BEAMISH), left to right: the linear array with a distant flag marking one of the Reftek/geophone stations (station A000); the recording tent – the petrol generator was located 50m from the tent; ploughing a furrow for the cable; inside the recording tent.*

The DAS datasets were recorded using a Silixa iDAS v2 interrogator using a 1kHz and 8kHz sampling rate for passive and active measurements respectively. A 6 channel tight buffered fibre- optic cable (PS-2S4M-1PU065-01-Y) was deployed, with the survey configure to measure strain-rate over 10m gauge lengths and a 1m channel spacing.

Table 2: *Summary of BEAMISH Survey Data acquired on the Rutford Ice Stream*

Survey name	**Start date* /file**	**End date /file**	**File prefix**	**iDAS used**	**Survey type**	**Comments**
Line1	11.1, 21:39 20200111_213809.171	16.1, 15:17 20200116_141640.134	BPL1	15040 (grey)	**Passive**	Total data: 770 + 153 **= 923 GB** Saved on: - HD-IDAS1: Line1_passive - HD-IDAS2: Line1_passive_2ndhalf
	16.1, 17:23 20200116_162221.407	16.1, 20:12 20200116_191043.901	BAL1	15040 (grey)	**Active (hammer)**	Total data: **111 GB** Saved on: HD-IDAS2: Line1_active
Line1 _triangle	16.1, 20:15 20200116_191314.623 (end grey iDAS) 17.1, 22:07 20200117_210618.732 (start black iDAS) 18.1, 00:14 20200118_001033.877	21.1, 21:31 UTC 20200121_171123.153	BPT1	First: 15040 (grey), then: 14029 (black)	**Passive**	Total data: 333 + 904 + 215 = **1452 GB** Saved on: - HD-IDAS2: Line1_traingle - HD-IDAS4: IDAS14029-black/ Line1_triangle_passive_part1 - HD-IDAS2: IDAS14029_black/ Line1_triangle_passive_part2 13 files of Line1_triangle_passive_part1 could not be copied to HD. See word document in HD-iDAS4 for details ~ 2h data gap in between the recordings of the two instruments due to changeover GPS antenna was removed in the morning of 20th Jan. Since then the iDAS14029 does not have GPS time any more!
Line2	21.1, 20:57 20200121_205639.032	21.1, 22:36 20200121_223601.952	BAL2	14029 (black)	**Active (explosions)**	Total data: **116 GB** Saved on: - HD-IDAS3: IDAS14029_black/ Line2_seismic_active
Line2 _hockey	21.1., 22:39 20200121_223916.506	24.1, 18:51 20200124_175124.151	BPL2H	14029 (black)	**Passive**	Total data: 806 + 61.7 = **867.1 GB** Saved on: - HD-IDAS3: IDAS14029_black/ Line2_hockey_passive_part1 - HD-IDAS2: IDAS14029_black/ Line2_hockey_passive_part2 Three screenshots comparing buried/not buried data on HD-IDAS3

* UTC of file saved on HDs – note that ‘real’ recording time is in file name; during our stay at BEAMISH local time was 3 hours behind UTC.

2.2.2 Data Examples

Examples from both passive and active surveys at Rutford are shown in Figures 4-6. For the passive example (Figure 4), the data has been preprocessed to enhance the S-wave arrival, while the reflection and refraction examples (Figures 5&6) are the unprocessed raw data.

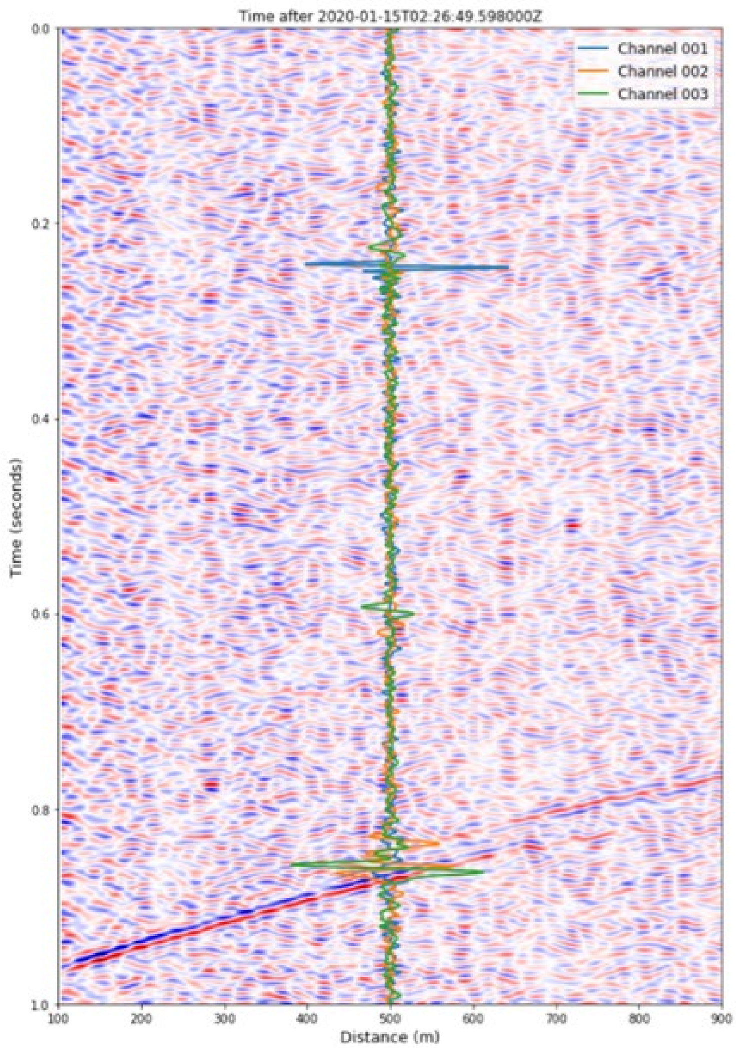
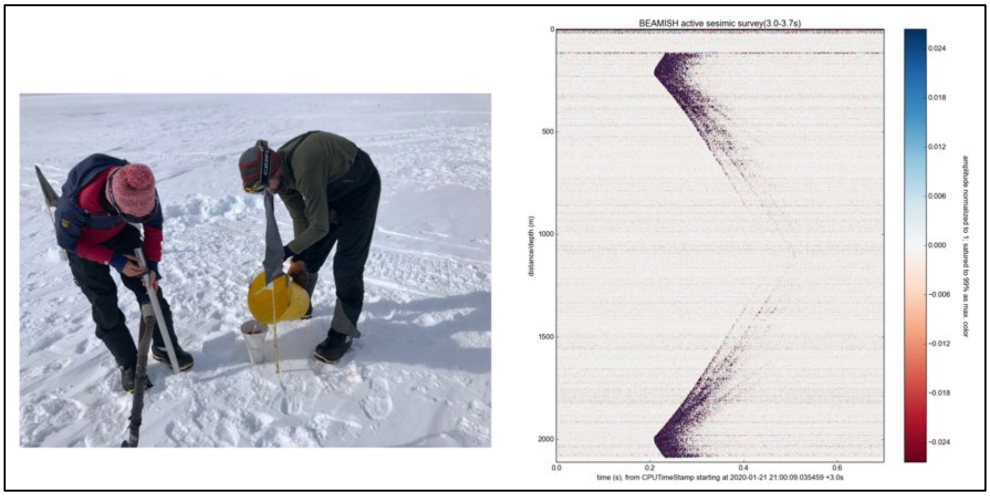


Figure 4: *An icequake from the bed of the ice (depth is roughly 2.5 km) recorded on Line 1 (linear array) and on a Reftek instrument (station A000). The P-wave arrival is not visible in the DAS data. This is because the low-velocity firn layer refracts the raypath to near vertical and the particle motion is perpendicular to the cable. Note the arrival of two clear shear waves. The ice column at Rutford is strongly anisotropic.*



- *Figure 5: (left) loading the 20 m deep shot holes with 3 grams of explosives. (right) The seismic reflection data recorded from one shot. Note that the data are reflection in the shot gather, because the 2 km cable wraps back on itself at 1km.*

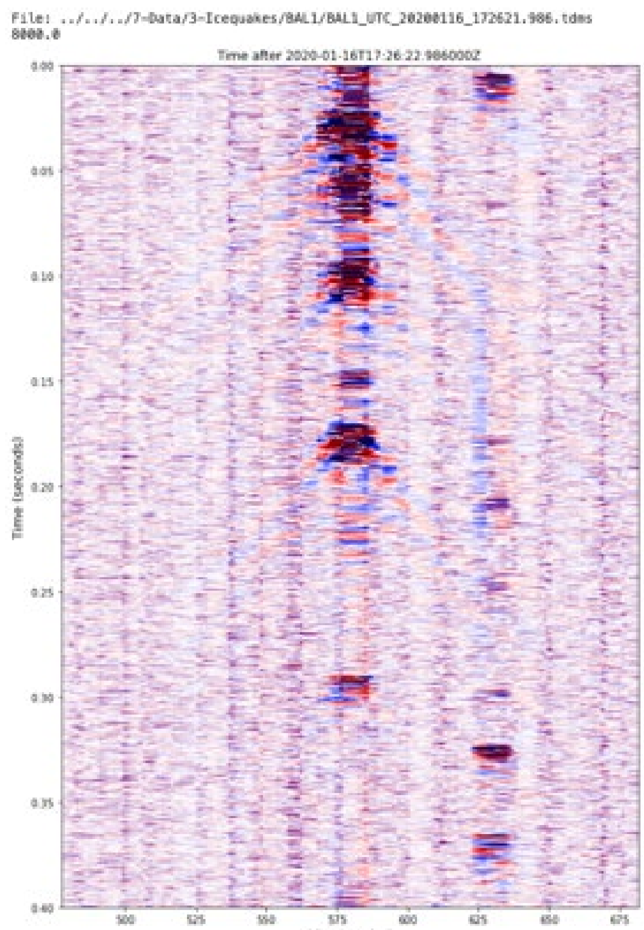


Figure 6: An example of unfiltered seismic refraction data acquired using a hammer and plate source.

2.3 Skytrain Ice Rise

2.3.1 Survey Configuration

As part of the WACSWAIN project (https://www.esc.cam.ac.uk/research/research-groups/wacswain) a 650m deep borehole was drilled at Skytrain during the 2018/19 season. A multi-mode fibre-optic cable was deployed in the borehole and used as a Distributed Temperature Sensor (DTS). We revisited the site in 2020, acquiring a walkaway Vertical Seismic Profile (VSP) survey using DAS acquisition. DAS data was acquired using a Silixa iDAS v2 interrogator connected to a DNS-4873 Sensornet fibre optic cable (Appendix A). Shots were acquired along three walk-away lines which were orientated at 40, 85 and 130 degrees from the borehole, with shot points located every 50m from 0 to 600m (Figure 7).

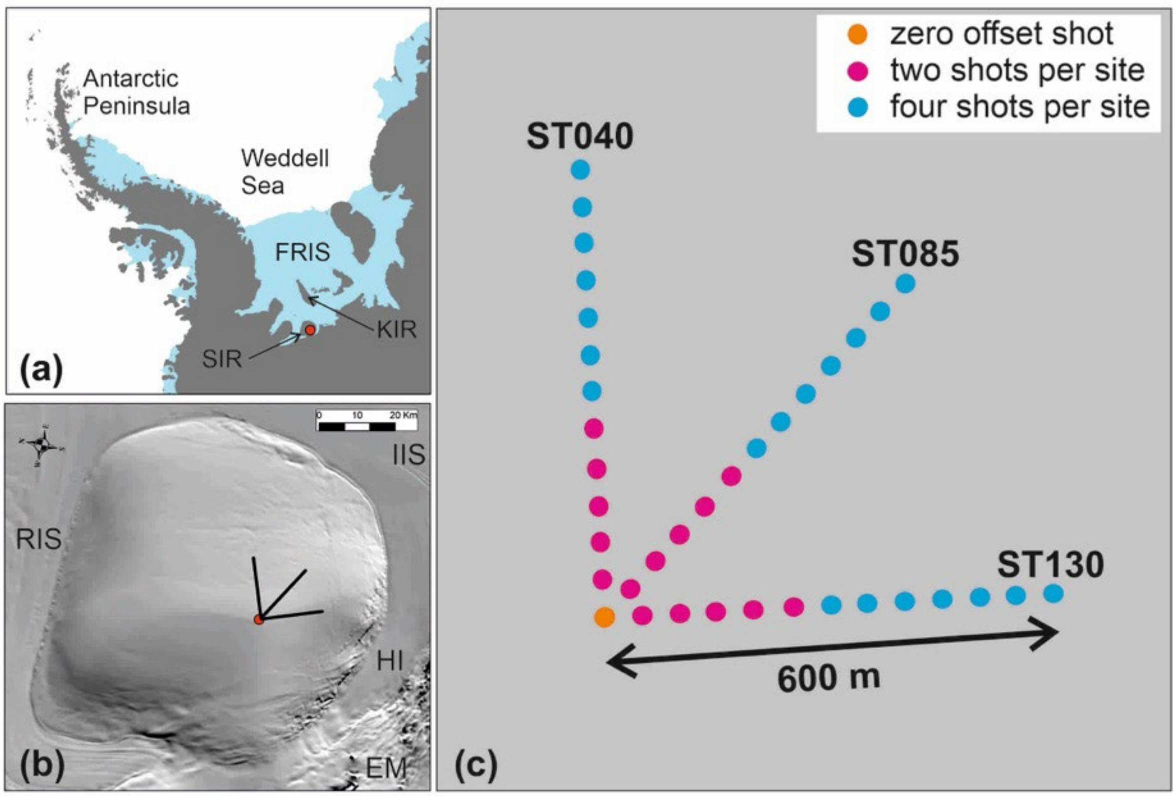


Figure 7: *a) & b) Survey location indicated by red dot c) Schematic diagram of field setup at Skytrain. Walk-away VSPs were acquired in 3 directions (040, 085, 130 degrees). Shots were acquired every 50m from 0m to 600m. Generator is 50 m from the recording tent.*

Figure 8: *The field setup at the Skytrain Ice Rise. The interrogator is house in the tent and powered by a petrol generator located 50m away. The large green Pellican Case house the DTS equipment, which is powered by the solar panels. Over 600m of cable is deployed in a vertical borehole marked by the flag behind the Pellican Case*

2.3.2 Data Example

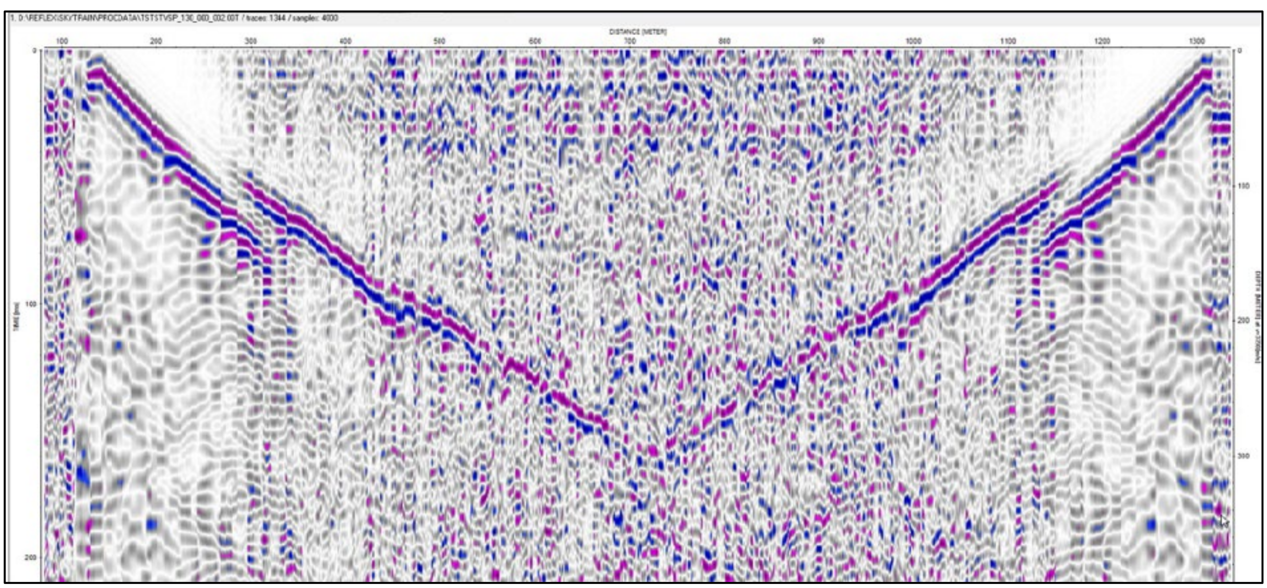
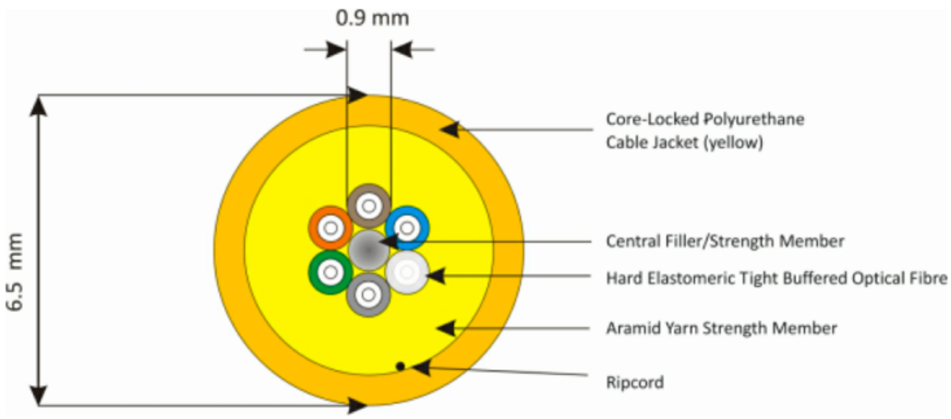


Figure 9: *An example of the data recorded of a zero offset shot. Note that the data are reflected in the section, as the cable runs down and up the borehole. The hole was filled with drilling fluid up to a depth of ~300m. The hole above this is empty.*

3 Data Access

Raw data was acquired in Silixa's tdms data format, with the data volume for both surveys totaling approximately 8TB. The original hard drives are held by BAS with a copy the data archived on the University of Bristol's Research Data Storage Facility (RDSF).

Appendix A: Cable Configurations



* Drawing not to scale

Typical characteristics

Fibre Code/Type	OM2/Multimode		Singlemode / ITU-T G.652.A	
Fibre Count	4		2	
Core Diameter	50 µm		9 µm	
Cladding Diameter	125 µm		125 µm	
Primary Coating Diameter (UV cured acrylate)	500 µm		500 µm	
Secondary Buffer Diameter (hard elastomeric)	900 µm		900 µm	
Numerical Aperture	0.20		--	
Proof Test Level	100 kpsi		100 kpsi	
Wavelength	**850 nm**	**1310 nm**	**1310 nm**	**1550 nm**
Maximum Attenuation	3.5 db/km	1.5 dB/Km	0.5 dB/Km	0.5 dB/Km
Bandwidth	500 MHz-Km	500 MHz-Km	-	-
Nominal Zero Dispersion Slope			.092 ps/(nm^2 Km)	

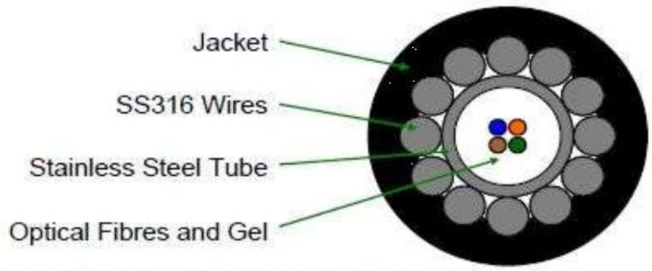
Mechanical Properties

Cable Diameter	6.5 mm (0.26 in)
Total Cable Weight	38 kg/km (26 lbs/1000')
Installation:	
Max. Tensile Load	1,800 N (360 lbs)
Min. Bend Radius	9.6 cm (3.8 in)
Operating:	
Max Tensile Load	600 N (130 lbs)
Min Bend Radius	6.5 cm (3.9 in)
Impact Resistance	1500 impacts
Crush Resistance	1800 N/cm
Operating Temperature	-55ºC to +85ºC
Storage Temperature	-70ºC to +85ºC

Figure A1: *Cable specifications for Rutford deployment* - 6 channel tight buffered fibre-optic cable (PS-2S4M-1PU065-01-Y).

sensornet

DNS-4873 2.4/2.0mm 316 SS tube, hydrogen scavenging gel, 2 x 50um MM fibre, armoured with 0.6mm SS wires, HDPE jacketed to 6mm



*Drawing is representative of cable product type. Please see Tube Details for specific information.

Dimensions		mm	inches
Inside Diameter		2.00	0.079
Outside Diameter		2.40	0.094
SS Wire Diameter		0.60	0.024
OD Over Wire Package		3.60	0.142
Jacket Diameter		6.0	0.236
Jacket Material	HDPE		
Stainless Steel Type	316		
Gel Type	Hydrogen Scavenging		
Total Fibre Count	2		
Fibre Type	2 x 50um MM fibre,		

Dimensions	Metric	English
Weight	63.7 kg/km	42.8 lbs/ kft
Breaking Strength	525 kg	1157 lbs
Yield Strength	450 kg	992 lbs
Strain @ Yield	0.429 %	0.429 %
Maximum Tensile Load	315 kg	694 lbs
Static Bend Radius	150 mm	5.9 in
Dynamic Bend Radius	240 mm	9.4 in
Temperature Rating	-40 to 85 °C	-40 to 85 F

NOTE: Assumes fibre tension of 0.2% for the Maximum Tensile Load rating

Figure A2*: The specifications for the fibre-optic cable (multi-mode) deployed at Skytrain in the 2019 field season.*

Appendix B: Rutford Ice Stream Field Notes

*1) Line1 – files prefixed BPL1 (B*EAMISH *P*assive *L*ine *1)*

Time recorded: 11.1-16.1, iDAS 15040 (grey pelicase)

Additional notes:

- Only recorded using first 1km of cable, as we didn't realise that the fibre runs there and back.
- Mon., 13th Jan., ~13:30-14:30 UTC: we walked along the cable and covered some spots which recorded noisy data with snow (see folder 'iDAS_line1_badSpots_13Jan' in Sofia's photos)
- Wed., 15th Jan., data gap of ~3 hours as iDAS software crashed

*2) Active hammer iDAS survey along Line1 – files prefixed BAL1 (B*EAMISH *A*ctive *L*ine *1)*

Thursday, 16.1.2020, iDAS 15040 (grey pelicase)

Parameters: 8000 Hz sampling rate, 4x decimation, 4s file size

Additional notes:

- We first tried to sample with 16000 Hz. A large amplitude spike appeared in the data while running the installation wizard. This was potentially created as the laser did not have enough energy for these settings (according to Andy Clarke). Putting the sampling rate to 8000 solved this problem.
- Alex on hammer for first 7 shots, Mike on the rest.
- Shot spacing every 50m, as measured by tape measure.
- Recording on full 2000m of cable (2 x 1km)

Note that all times are local and not UTC

0 m 2 shots 14.01

50 m 2 shots 14.07.43 14.07.51

100 m 3 shots 14:09.52 14.07.54 ??

150 m 3 shots 14.12.30 …

200 m 2 shots 14.14.00 …

250 m 2 shots 14.15.00 …

300 m 2 shots 14.18 …

350 m 2 shots 14.20 …

400 m 3 shots 14.21 …

450 m 2 shots 14.23 …

500 m 3 shots 14.24.30 … (note, cable visible)

550 m 2 shots 14.26.20 …

600 m 3 shots 14.28.00 …

650 m 2 shots 14.29.40 …

700 m 2 shots 14.31.00 …

750 m 2 shots 14.32.20 …

800 m 2 shots 14.33.40 …

850 m 2 shots 14.35.00 …

900 m 4 shots 14.36.30 …

950 m 2 shots 14.38.40 …

1000 m 2 shots 14.41.00 …

*3) Line1_Triangle (1/3 along Line1, then cable was bend downstream into a triangle, leading back to the iDAS tend) – files prefixed BPT1 (B*EAMISH *P*assive *T*riangle *1)*

Time recorded: 16.1 (19:00 UTC) -21.1 (~17:05 UTC), first iDAS 15040 (grey pelicase) then iDAS 14029 (black pelicase).

Additional notes:

- 8pm local on 17/01/20: iDAS units were exchanged
- 9am-ish (local) 18/01/20: iDAS stopped recording because the disk was full; deleted some legacy data and restarted at 2.30 pm (local)
- 2.30 pm (local) 18/01/20: exchanged generator cable – went from 50m extension to a 5m extension – look for any degradation in data quality!
- Mon., 20.1.2020 in the morning (~7am local time): GPS antenna was dismantled
- Mon., 20.1.2020, 19:26: iDAS stopped operating (generator out of petrol) and was restarted (now without GPS time as antenna was taken away the day before!)

4) Active explosion iDAS survey along Line2 (parallel to parts of flow-parallel seismic line)

Tuesday, 21.1.2020, iDAS 14029 (black pelicase)

Parameters: 8000 Hz sampling frequency, GPS trigger active, continuous mode, external clock, 30 s file size files

Additional notes:

- 5 shots a 300 g explosives at 20 m depth (drilled and prepared with the hot water drilling system as for the seismic survey). iDAS was operating without GPS antenna on internal computer time.
- At ~20:57 UTC Alex was touching fibre at its start point along the seismic line to highlight its location (as the first ~80 m of cable are not parallel to the seismic line but leading into the iDAS tend)
- Shot times:

Shot number	Shot ID*	GPS time	iDAS internal computer time
1	Fibre3120	20:57	21:00:13
2	Fibre4080	21:09	21:12:13
3	Fibre5040	21:26	Etc.
4	Fibre6000	21:35	
5	Fibre6960	21:42	

*for comparison to seismics; shot locations are saved under this name in Alex' differential GPS files as well

*5) Line2_hockey – files prefixed BPL2H (B*EAMISH *P*assive *L*ine *2 H*ockey*) – follows 2/3 along line2, the last 1/3 of the cable is bend by 40 degrees towards the mountains*

Time recorded: 21.1-24.1, iDAS 14029 (black pelicase)

Additional notes:

- No GPS antenna attached
- The cable was first deployed in the Skidoo track and not covered.
- Wed., 22.1, ~04:27 UTC: iDAS crashed due to writing error (see screenshots on HD-iDAS3), restarted at 10:13 UTC
- Wed., 22.1, ~13:00-16:40 UTC: starting to bury the cable (see folder 'iDAS_hockey_uncover_cover' in Sofia's photos). After ~2h there is a break of ~45 minutes, after the cable had been buried up to the kink. After burring the cable the Setup Wizard was re-run (last file with old settings: *20200122__165246.458; first file with new settings: *_165544.151)
- Fr., 24.1, ~17:50. Before dismantling the fibre, Alex' tapped the fibre at the starting point (when it starts running parallel to seismic line) and at kink to highlight the location of these two features. Then the measurement was stopped.

Some useful notes for handling the iDAS in Glacial conditions

- How to deploy cable: cable can be dragged very easy parallel to the direction it lies on the ground. E.g. if cable should be deployed in a kink. One person could stand in the corner and drag it from one direction while another person is pulling into the new direction. The hole created by the Skidoo skies is perfect to put the cable into it.
- Covered vs. uncovered: generally wind seems to be one of the largest noise sources. A loose cover of snow decreases noise level a lot. Generally small patches (e.g. 10-20 cm) of uncovered cable (or cable even in the air) do not matter.
- Unit was deployed in a mountaineering tent. Temperatures in the tent varied from 0degC to 40 degC. Difficult to get temperature stable.
- During most of the time at BEAMISH, the generator has been refuelled around 10:00, 19:00 and 02:00 UTC. This might be a noise source.
- The pig tail which has been used during the survey is marked with a black tape strap.

Figure B1. A photo of covered and uncovered portions of the fibre. Even a surficial cover of snow made a significant difference to noise levels.

Appendix C: Skytrain Ice Rise Field Notes

iDAS Walkaway VSP (Field Notes)

Date data acquired: 23/01/20 – 24/01/20

Weather: 23/01/20 late in the evening, sudden drop in wind speed to 5 knots, unlimited visibility; 24/01/20 winds 20-25, visibility 200m. Cold both days.

iDAS unit is the one in a grey case (need to get S/N).

iDAS unit housed in a mountaineering tent located just north geographic (downwind) of the pit around the borehole

Data stored on RAID in directory /BEAMISH/SkytrainVSP; individual files are prefixed with STVSP130 or STVSP040 or STVSP085 (need to check this). STVSP130, STVSP130.2 and STVSP130.3 denote the take 1, take 2 and take 3 as described below. Generated roughly 388 GB of data.

Source: hammer and plate. JMK hammered first, AF hammered second.

Stations: 0 m (acquired only once) 1 shot each (JMK and AF); 50 m 1 shot each; 100 m 1 shot each; 150m 1 shot each; 200 m 1 shot each; 250 m 1 shot each; 300m 1 shot each; 350 m 1 shot each; 400 m 2 shots each; 450 m 2 shots each; 500 m 2 shots each; 550 m 2 shots each; 600 m 2 shots each. Note slightly different for STVSP130 and STVSP130.2, as noted below.

Line 130 – stations surveyed using compass and tape measure; Line 040 and 085 surveyed using compass and handheld GPS, as it was far too windy to use tape measure.

Receiver: fibre is down borehole to base of ice (~650 m deep). Note that cable is down to bottom and back to top, so all shots are recorded on both legs. Therefore, we effectively acquired either 4 shots for near-offset shots and 8 for offsets >350 m. Gauge length is 10 m.

17:00ish – setup iDAS. Confirmed that one pigtail is broken, fortunately second pigtail was okay. Power from generator nearly 50 m away in a direction roughly 50-60 deg from magnetic north.

Note: signal is weaker on return leg of fibre, step jump down at ~600 m is visible on Step 3 of setup wizard.

18:31 – practice hammer; confirmed visible on display

Reftek attached to battery and using 3C SP sensor. Started using broken battery, as it still had 12v charge. Changed to larger Sunlight battery for Take 2 onwards.

Reftek moves to each SP and the geophone is deployed next to the plate. Both iDAS and Reftek have GPS lock, so should be able to get time zero for shots.

Line 130 - Take 1 – (roughly perpendicular to the trend of the main line)

Rough shot times:

18:34 0 m; 2 shots (JMK then AF)

18:41 50 m; 2 shots

18:51 100 m; 2 shots

18:54 150 m; 2 shots

18:57 200 m; 2 shots

19:01 250 m; 2 shots

19:04 300 m; 2 shots

19:06 350 m; 2 shots

19:11 400 m; 2 shots

Stopped: realised the Reftek kept powering down and then restarting. Battery voltage reduced to 8v, presumably due to travel damage. Not sure how much useful data were acquired.

Line 130 - Take 2 – late evening and getting tired (22:18)

Replaced battery with large Sunlight.

Rough shot times:

22:35 0 m; 2 shots (JMK then AF)

22:36 50 m; 2 shots

22:37 100 m; 2 shots

22:39 150 m; 2 shots

22:40 200 m; 2 shots

22:41 250 m; 2 shots

22:42 300 m; 2 shots

22:45 350 m; 2 shots

22:46 400 m; 2 shots

22:47 450 m; 2 shots

22:50 500 m; 4 shots (2 JMK then 2 AF)

Note: two earlier shots with no Reftek geophone planted

22:53 550 m; 4 shots

22:57 600 m; 4 shots

Sadly, realised that 'laser arm' on iDAS was not lowered into horizontal position!

Line 130 - Take 3 – morning of 24/01/26

Rough shot times:

Start: 11:09

Finish: 11:31

2 shots: 0 – 350 m; 4 shots: 400 – 600 m

Line 040 – roughly parallel to trend of main GPS, ApRES line

Start: 12:40

Finish: 13:00

Station distances determined by handheld GPS unit. Not sure of accuracy.

Line 085 – bisects two other lines

Start: 13:20

Stop: 13:44

Station distance determined by handheld GPS unit.