Deliverable 1.1 Addendum 2:

DAS field dataset to compare technologies and deployment scenarios

CaMI Field Research Station, Canada, Dataset

DigiMon

Digital monitoring of CO_2 storage projects

Prepared by:
Dr A Butcher (University of Bristol)
Dr V Vandeweijer (TNO)
Prof J-M Kendall (University of Oxford)
Dr W Zhou (University of Bristol)
Dr A Stork (Silixa Ltd)

DigiMon Deliverable D.1.1 Version 1,
September 2021

Revision

Version	Date	Change	Page
1.0	15.09.2021	First version	All

Document distribution

ACT Coordinator

- Research Council of Norway

ACT national funding agencies

- Forschungszentrum Jülich GmbH, Projektträger Jülich, (FZJ/PtJ), Germany.
- Geniki Grammatia Erevnas kai Technologias/The General Secretariat for Research and Technology (GSRT), Greece.
- Ministry of Economic Affairs and Climate/Rijksdienst voor Ondernemend Nederland (RVO), the Netherlands.
- The Research Council of Norway (RCN), Norway.
- Gassnova, Norway.
- Development and Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI), Romania.
- Department for Business, Energy and Industrial Strategy (BEIS), UK.
- Department of Energy (DoE), USA.

DigiMon partners

- NORCE Norwegian Research Centre AS
- OCTIO Environmental Monitoring AS
- NTNU Norwegian University of Science and Technology
- University of Bristol
- University of Oxford
- CRES Centre for Renewable Energy Sources and Saving
- Helmholtz–Centre for Environmental Research
- Sedona Development SRL
- TNO Nederlandse Organisatie voor toegepast -natuurwetenschappelijk Onderzoek
- Geotomographie GmbH
- LLC Lawrence Livermore National Security
- SILIXA LTD
- EQUINOR ASA
- REPSOL –NORGE AS

Table of contents

1 Introduction

This report describes a Distributed Acoustic Sensor (DAS) dataset acquired by DigiMon partners at the Containment and Monitoring Institute's (CaMI) Field Research Station (FRS), Canada, between 6th to 10th September 2021. The field dataset contributes to the Deliverable D1.1 of the DigiMon project (DAS field dataset to compare technologies and deployment scenarios), which supports tasks 1.2 and 1.3 of the project.

The objective of the DigiMon project is to develop an early-warning system for Carbon Capture and Storage (CCS), which utilises a broad range of sensor technologies including DAS. While the system is primarily focused on CCS projects located in shallow offshore environment of the North Sea, it is also intended to be adaptable to onshore settings. Some of the key areas that the systems will monitor include the movement of the plume within the reservoir, well integrity, and CO2 leakage into the overburden. A combination of both active and passive seismic methods will be deployed to track the movement of CO2, for example seismic reflection to image seismic velocity changes and microseismics to capture fault activation. Acquiring seismic surveys using DAS is highly novel and offers cost-effective approach which can significantly increase the spatial resolution of the survey data; however, it has had limited use in the operational environment with several technical challenges still needing to be resolved, such as the transfer function of DAS.

CaMi FRS was selected as a field test location as the site has been specifically established to advance the development of monitoring technologies and protocols for CCS operations. At CaMi FRS, several different monitoring arrays have been installed which are directly applicable to DigiMon. This includes a 5km loop of DAS optical fibre, located with a 1.1 km surface trench and two observation wells, an array of surface and borehole geophone nodes, and 6 broadband seismometers operating by the University of Bristol. This monitoring infrastructure has been primarily installed to monitor CO2 injections into the Basal Belly River sandstone formation at approximately 300m below ground level. Injection of CO2 began at FRS in 2019 and during this time microseismic events have been recorded, albeit at shallower levels than the injection point. The site therefore provides a potential DAS dataset which contains both active and passive measurements for the DigiMon project. The abundance of instrumentation including DAS, geophones, and broadband seismometers provides a unique chance to test the capacity of these instruments for C02 storage monitoring.

Plate 1: CaMI's Field Research Station, Canada, with mini-vibroseis truck in the foreground and CO2 storage tanks and research compound in the background.

1.1 Survey Objectives

The primary purpose of the fieldwork at CaMi FRS is to provide a dataset which supports task 1.2 ‘determining the DAS transfer function’ and task 1.3 ‘develop DAS data processing techniques and workflow’ of the DigiMon project. A secondary objective is to test the use of autonomous seismic nodes in monitoring CO2 injection, but also as a calibration tool for DAS surveys. The objectives of the survey are:

1. Microseismic dataset, detection of CO_2 injection:
    - Testing processing workflow, e.g. testing detection algorithms.
    - Temporarily densify the broadband network with 3C nodes.
2. Dataset for ambient noise interferometry:
    - Classify noise sources and compare response on broadband and fibre arrays.
    - Joint cross-correlation of nodes/Broadband seismometers and fibre.
3. Transfer Function:
    - deconvolving response from co-located nodes.
4. Response of straight and helical wound fibre:
    - Sensitivity of different fibre configurations.
5. Near-surface S-wave model. 3D VSP.

2 Description of Dataset

2.1 Site Description

The CaMI Field Research Station is located within the Canadian province of Alberta (Figure 1), approximately 30km south-west of Brooks in the County of Newell. The site is situated in relatively flat prairie lands, which have very minimal topographic variations. Within the centre of the site is a fenced compound which contains the main CO2 injection infrastructure, including the injection well, and two observation wells. Running through the compound is a 1.1km DAS trench which is centred on the injection well. Outside of the compound, six broadband stations surround the injection well, which were previously installed by the University of Bristol to monitor microseismicity and changes in the ambient noise field resulting from the CO2 injection.

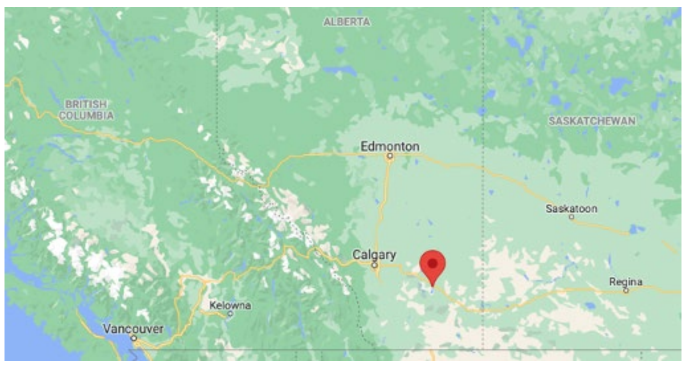


Figure 1: Location of CaMi's Field Research Station, Alberta, Canada.

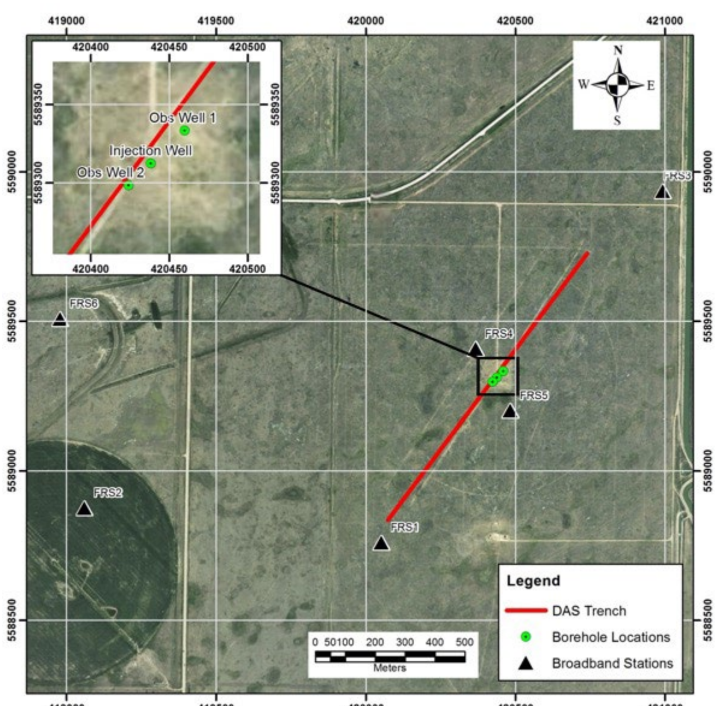


Figure 2: Layout of the CaMI Field Research Station, Alberta, Canada.

2.2 Geological Setting and CO_2 Injections

During the survey period, 452kg of CO_2 was injected into the Basal Belly River Formation at a depth of about 285m. The formation comprises of shoreface sands in the basal unit, overlain by coastal plain silts and coals which provide sealing capabilities (Figure 3). Two phases of CO_2 injection were conducted, with 308kg injected from 2021-09-07 17:29 to 2021-09-08 08:53, and 138kg injected between 2021-09-09 07:57 and 2021-09-09 15:43.

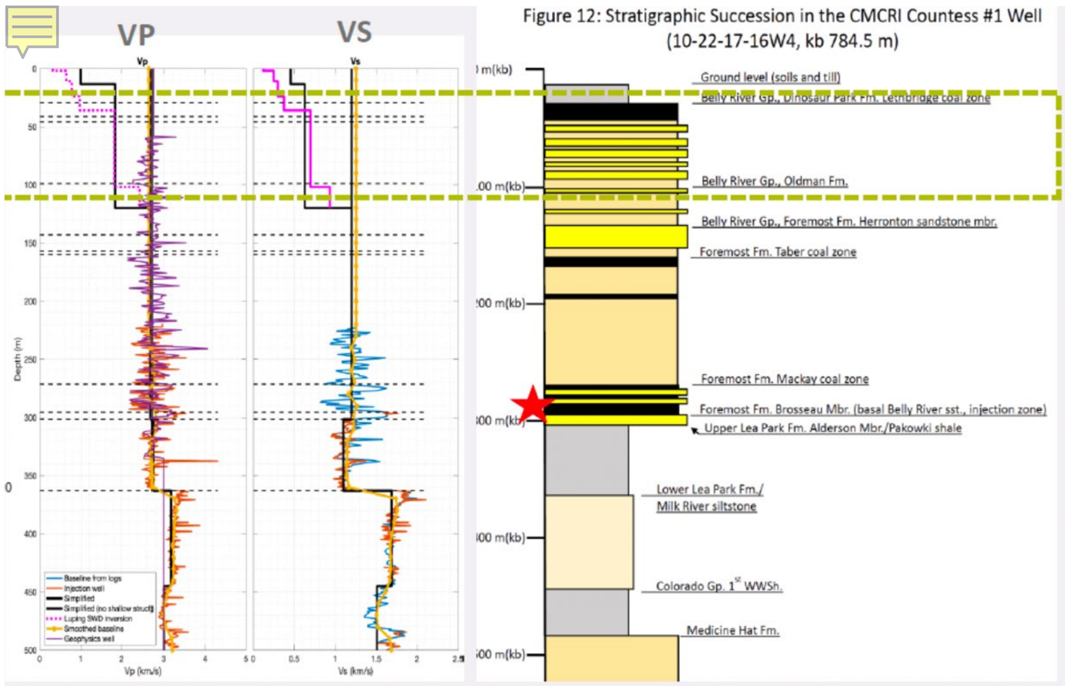


Figure 3: Geology underlying CaMI FRS.

2.3 Acquisition Timetable

Table 1 below shows the timeline for the survey acquisition at CaMI FRS.

Day	Date	Site Activities
1	06/09/21	Arrive on site; Survey in stations; Tap test DAS cable; Install 1C nodes along DAS trench; 23x 3C TNO nodes installed between 1C nodes.
2	07/09/21	6 TNO 3C nodes deployed as part of MS array; Vibroseis survey acquired along two lines; PPV meters deployed; CO2 injection commenced at ~17:29pm.
3	08/09/21	ICIS propane P-wave source survey acquired.
4	09/09/21	ICIS S-wave survey acquired; CO2 injection commenced at 07:57am.
5	10/09/21	1C and 3C node decommissioned ; Broadband stations downloaded.

Table 1: Survey timeline

2.4 Survey Personnel

- J-Michael Kendall, University of Oxford
- Robert Kendall, Global Seismic (GSR)
- Ben Broman, Silixa
- Vincent Vandeweijer, TNO
- Marie Macquet, Franki Race, Malcolm Bertram, Don Lawton – Carbon Management Canada (CMC)

Plate 2: DigiMon Survey team supported by Carbon Management Canada.

2.5 DAS Array

Both linear and helical wound fibre optic cable is installed at FRS. This is configured as a 5km loop travelling from the recording cabin down the two observation wells, through a 1.1km trench and back to the cabin (Figure 4). The loop transitions between the linear and helical wound cable, therefore the raw data requires reordering into individual sections. The locations of these transitions were established through a tap test at the start of the survey (Table 2). The main transition points are overlain on a raw vibroseis shot gather in Figure 5.

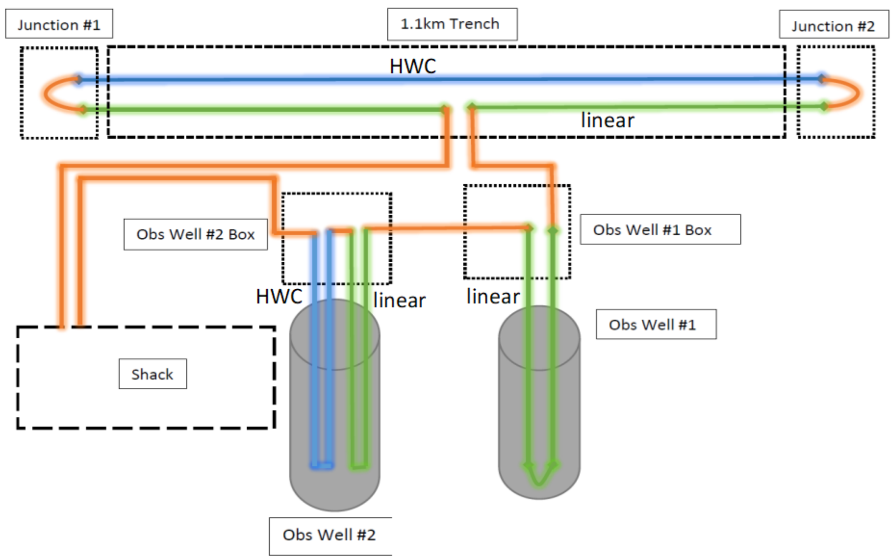


Figure 4: Schematic of DAS fibre configuration

	Tap Name	Timestamp	Receiver channel	Fibre Length (m)	Distance locs (m)
1	Top OBS Well 2 Helical downgoing	210149	74	75.79	
2	Top OBS Well 2 Helical upgoing	210149	811	827.75	751.96
3	Top OBS Well 2 straight downgoing	210319	823	840.5	12.75
4	Top OBS Well 2 straight upgoing	210319	1507	1538.84	698.34
5	Top OBS Well 1 straight downgoing	210824	1583	1616.44	77.6
6	Top OBS Well 1 straight upgoing	210824	2264	2311.68	695.24
7	Beginning of Horizontal Trench?	221101	2337	2386.19	74.51
8	SE horiz. Turnaround	213210	2926	2987.06	600.87
9	NE horiz. Turnaround	212035	4173	4260.65	1273.59
10	End of Horizontal trench	222158	4719	4817.62	556.97

Table 2: Location of tap tests along DAS loop

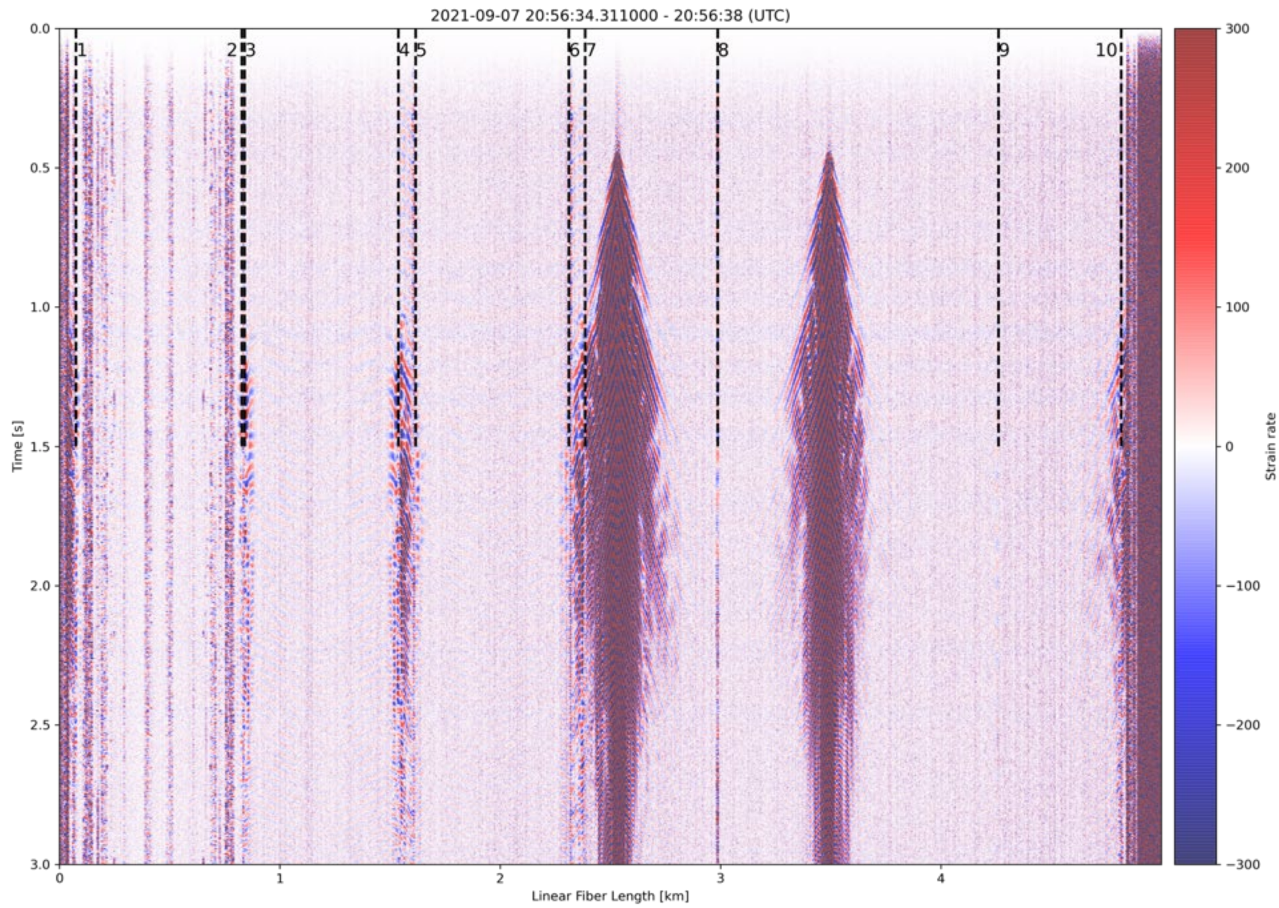


Figure 5: Raw vibroseis shot gather recorded of DAS array. Dash lines represent the locations of the tap tests.

2.6 DAS Instrumentation

During the survey period, continuous DAS measurements were acquired along the 5km fibre loop using a Silixa iDAS v2 interrogator. Strain rate measurements were made along the fibre using a 10m gauge length and a 1.020952m channel spacing (Table 2).

Setting	Value	Units
Sampling Frequency	1000	Hz
Time Decimation	16	
Laser Firing Rate	16000	Hz
Spatial Sampling	1.020952	m
Measure Length	5095.85	m
Continuous Mode	ON	
Data Output	Strain Rate	Proportional to nm/m/s

Table 3: Acquisition settings used for the iDAS unit during the survey period.

2.7 Node Array Locations

A combination of 1-component (1C) nodes from UoB/UoO and 3-component nodes from TNO were install during the fieldwork period. The majority of the nodes were located along the DAS trench in order to compare the response of the nodes and DAS (Table 4). In addition, six 3-component (3C) nodes were also deployed around the injection well to enhance the broadband array (Table 5).

Station	Line	Location	Node S/N	Notes
1	1	500	1416067	
2	1	450	1415940	
3	1	400	1415997	Partially Buried
4	1	350	1415972	Buried
5	1	300	1415744	Buried
6	1	250	1416021	
7	1	200	1416102	
8	1	150	1416080	
9	1	100	1415760	
10	1	50	1415746	
11	1	0	1415949	Centre of line
12	1	-50	1415737	
13	1	-100	1416001	
14	1	-150	1416117	
15	1	-200	1416049	
16	1	-250	1415959	
17	1	-300	1416054	
18	1	-350	1416014	
19	1	-400	1416105	
20	1	-450	1415782	
21	1	-500	1416058	
22	1	-550	1415946	
I1	1	-10	1415808	Infill stations centred on stn 11
I2	1	-8	1415969	
I3	1	-6	1415784	
I4	1	-4	1415965	
I5	1	-2	1415774	
I6	1	2	1416076	
I7	1	4	1416088	
I8	1	6	1416071	

Table 4: Location of the UoB 1C seismic nodes along the DAS trench.

Along with the UoB/UoO 1C nodes, 30x 3C TNO nodes were also deployed midway between 1C nodes.

Station	Latitude	Longitude
1	50.452802	112.120785
2	50.452680	112.124167
3	50.449379	112.123871
4	50.448026	112.112690
5	50.451046	112.113664
6	50.451043	112.116415

Table 5: Location of the 6 TNO 3C seismic nodes deployed to complement the broadband array.

2.8 Source Locations

Two different seismic sources were used during the survey, a mini-vibroseis and an Internal Combustion Impulse Source (ICIS) propane driven hammer. The vibroseis source was used to generate predominantly P-waves at regular shot locations along the DAS trench and at orthogonal angles from the centre point of the trench (Figure 6). The ICIS propane driven hammer was configured to generate P-waves at the same locations as the vibroseis shots along the DAS trench. Additionally, a modified ICIS source was used to generate S-waves and recorded by a densified array of seismic nodes near the injection well.

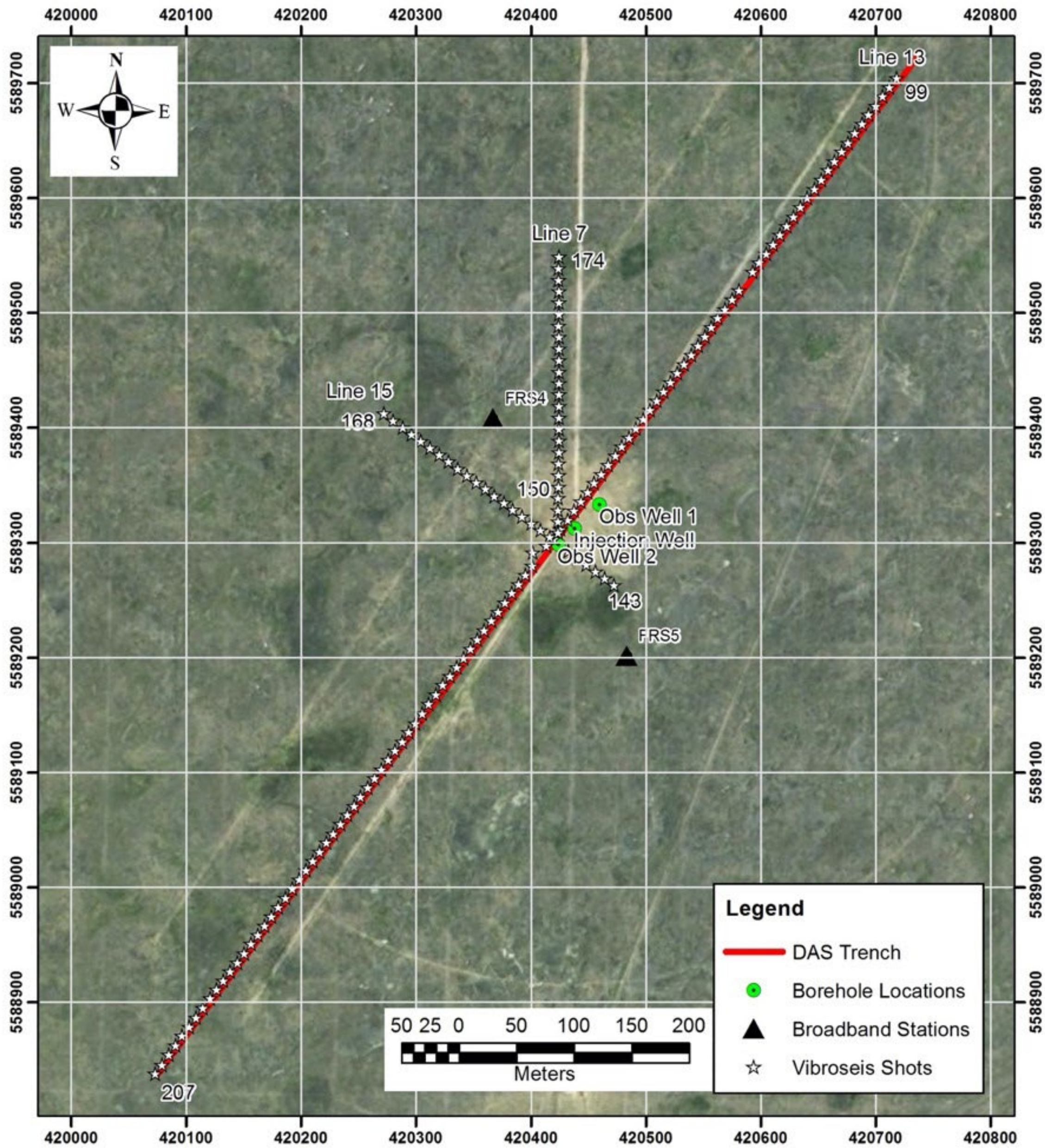


Figure 6: Source locations of the mini-vibroseis and ICIS surveys.

2.8.1 Vibroseis Survey

Three separate survey lines were acquired, with the Line 13 located along the DAS trench, Line 15 positioned perpendicularly to the trench and Line 7 orientated at a 45degree angle from the centre of the trench (Figure 6).

The mini-vibroseis source generated a 16 second tapered sweep, which generated signals between 10Hz and 150Hz (Figure 7), with a quarter-second taper at the beginning and end of the chirp. When cross correlated from the raw data, the signal from this source is observed across the majority of the DAS array (Figure 8), with clear direct and surface waves present in the dataset.

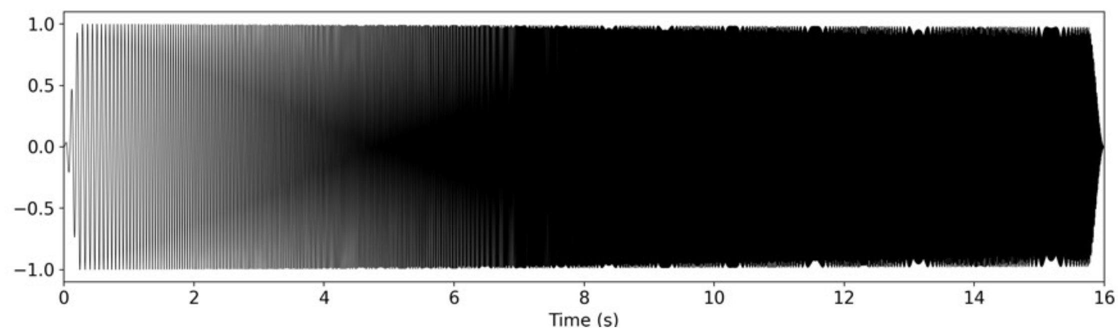


Figure 7: Normalised vibroseis source sweep.

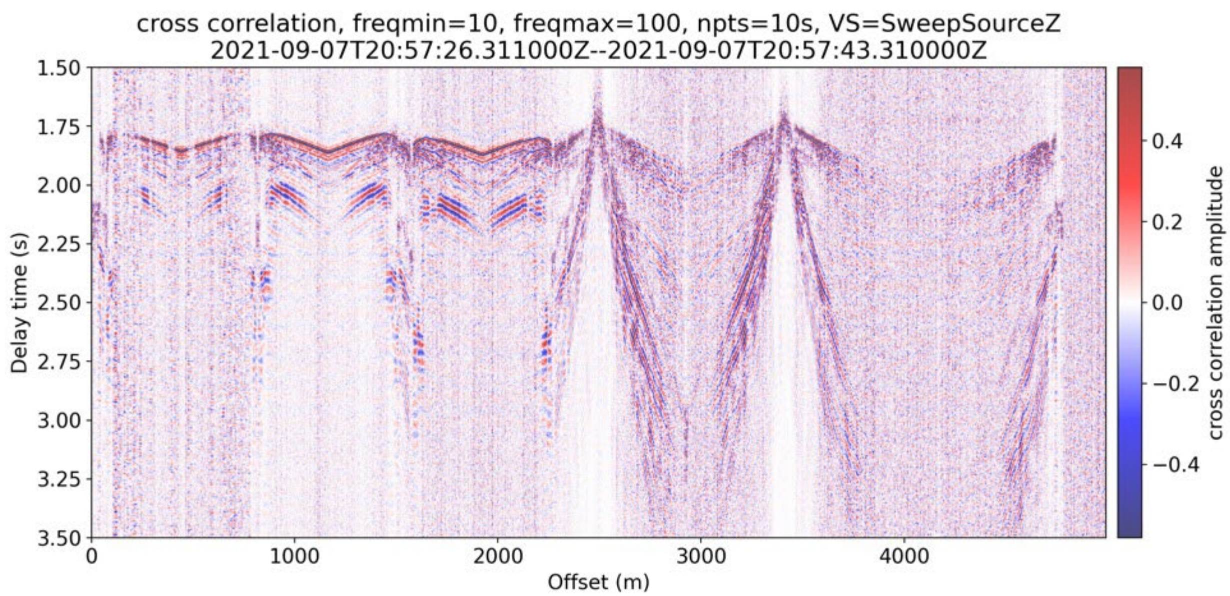


Figure 8: Source corrected data. Signals are present across the majority of the DAS loop.

2.8.2 ICIS Propane Survey

The ICIS is a human-portable impulse source powered by propane and oxygen fuel, which depending on the orientation of the source, can be used to produce both P- and S-waves (Plate 3). The source produces a peak force of 5600 N which is easily repeatable allowing for multiple shots at a given location. An example shot gather recorded on the 3C nodes in shown in Figure 9. Timing is controlled by a GPS-driven high-accuracy clock which can provide time- stamping to 1 μs. For the P-wave survey, 10 shots were made at 108 different shot points. The S-wave survey consisted of 4 shots at 11 shotpoints.

Plate 3: ICIS propane source deployed at CaMi FRS.

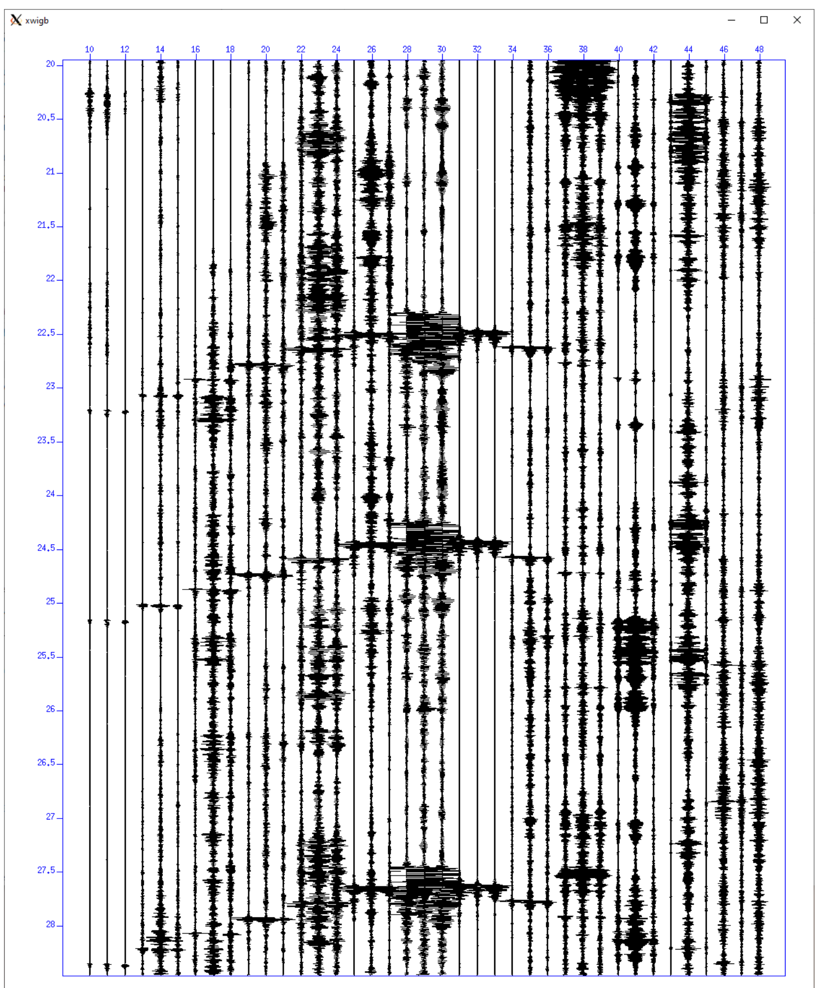


Figure 9: Shots generated by ICIS source recorded on TNO 3C nodes.

3 Data Access

Raw data were acquired in Silixa's tdms data format, with the data volume from the DAS survey totalling approximately 3TB. The original hard drives are held by UoB with a copy the data archived on the University of Bristol's Research Data Storage Facility (RDSF).

4 Recommended Applications

The CaMi FRS dataset comprise of continuous data recorded over 3-4 days. The DAS network was complemented by 1- component and 3-component geophones which were deployed along the DAS survey line. In addition, broadband data is recorded outside of the 5km fibre loop. Along with passive monitoring, a series of active seismic sources were made along linear DAS array. Some examples of applications for this dataset include:

- assessment of using DAS for active surveys, e.g. seismic refractions, MASW;
- sensitivity of straight fibreoptic cables to seismic signals;
- development of a microseismic workflow, e.g. event detection;
- research on the transfer function and response of DAS;
- seismic magnitudes estimation from DAS;
- development of ambient noise DAS processing workflow;
- optimum array geometries for DAS.

Appendix A: Cable Configurations

DAS at FRS : Helical Wound Cable

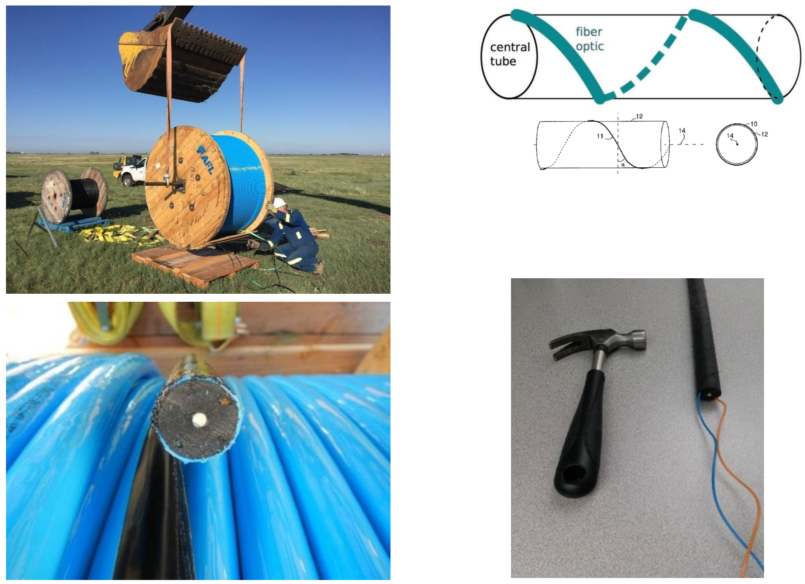


Figure A1: Cable specifications for Helical Wound Cable

DAS at FRS : Straight fibre in Obs well #1 and #2

Combined DTS, Heater, DAS
Hybrid copper/fiber-optic cable

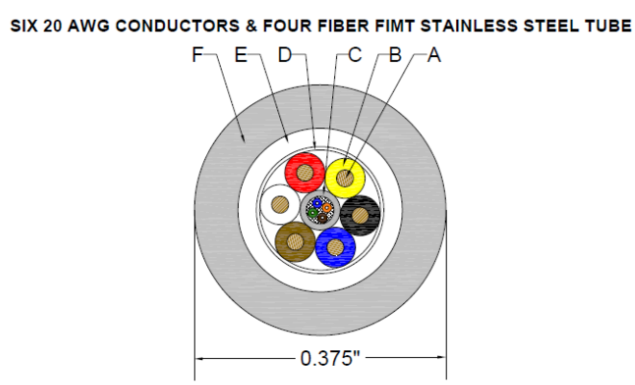


Figure A2: The specifications for the linear fibre optic cable.

Appendix B: ICIS Technical Information

ACQUISITON – REFRACTION – INFILL – IMPULSIVE SURFACE SOURCE

ICIS

Internal Combustion Impulse Source

ICIS is a compact, man-portable impulsive source available from GSR, as a solution for infill where access for conventional sources is restricted, and for low-impact surveys for shallow targets. The source is self-contained, robust and reliable which makes it easy to deploy in remote areas and challenging environments. It has been tested in temperatures down to-40°C making it suitable for winter use in North America and the Arctic. It is powered by readily-available propane and oxygen fuel which provide an extended operating life of 3000 shots between refueling.

ICIS can be easily integrated with other sources for infill thanks to a custom shooting system compatible with Sercel SN408 or SN428 recording systems which allows the observer to switch rapidly from explosive or vibroseis mode to ICIS on a shot-by-shot basis. A GPS-driven high-accuracy clock and a specially developed impact sensor provide accurate time-stamping and recording of timebreak information to better than 1 μs, allowing GPS Time-Stamps for all Nodal Systems.

BENEFITS:

- Low environmental impact: operate in areas with strict environmental regulations
- Efficient: high-productivity for cost-effective infill shooting or shallow high-resolution surveys
- Versatile: integrates seamlessly with conventional sources for infill
- Convenient: man-portable, readily available fuel, extended operating life
- Reliable and Safe: designed and tested for harsh conditions with rigorous HSE compliance

IDEAL FOR 2D/3D REFLECTION AND REFRACTION SURVEYS IN:

- Heavy oil infill for riparian zones and other areas with strict environmental regulations
- Shallow oil and gas (e.g. Coal Bed Methane)
- Mineral exploration
- Near-surface characterization
- Structural and engineering surveys

GSR
GLOBAL SEISMIC REPAIRS INC

ACQUISITION – REFRACTION – INFILL – IMPULSIVE SURFACE SOURCE

globalseismicrepairs.com

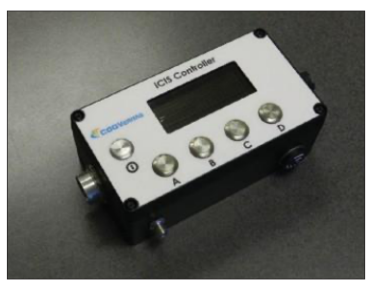
APPLICATIONS:

In the heavy oil regions of Canada, there are many riparian areas (rivers and water margins) where environmental regulations restrict the use of mechanical transportation. The consequence is that gaps are left within surveys because conventional sources cannot be deployed. Hand-drilling is allowed in some areas but is expensive and slow and may also become restricted. By deploying ICIS, infill can be economically acquired while respecting the environmental regulations to mitigate the imaging problems associated with lack of coverage.

ICIS is also ideal for low-impact and efficient shallow target exploration. With reduced energy output depth of penetration will depend on geology. However, with its accurate time break ICIS shots can be stacked to provide increased signal-to-noise ratio and to achieve better penetration. For example, ICIS has been demonstrated on 300-450 m deep targets on a coal project in South Africa. Other applications where ICIS can be considered include near-surface surveys and structural engineering surveys.

ICIS SpECIFICATIONS

Peak Force:	1275 lbs (5600 N)
Timing Accuracy:	< 1 µsec
Shooting cycle:	2.5 sec (min)
Dimensions:	25 cm (10") X 44 cm (18") X 114 cm (45")
Weight:	49.5 kg (109 lbs) - with Fuel/Oxygen canisters
Fuel:	Propane, Propylene, Butane/IsoButane mix
Canister/Fitting:	Fuel: CGA 600, EN417 Oxygen: M4A Medical w/CGA-870Toggle Valve, 40g (1.4 oz) w/CGA-601
Capacity:	~3000 Hits per 465g (16 oz) Propane canister
Power:	12VDC Decoder: 9W (775mA) - quiescent 14W (1150mA) - OCXO heat up 13W (1075mA) - Radio TX ICIS Unit: 2W (150mA) - quiescent 35W (2900mA) - firing
Radio Band:	VHF/UHF
Radio Power:	5W



WORLDWIDE HEADQUARTERS

Global Seismic Repairs
4405A-75 Ave SE
Calgary, AB, CANADA
T2C-2K8

Doug Goble
Office: +1 403 252-7552
Cell: +1 403 660-0861
dougg@globalseismicrepairs.com
www.globalseismicrepairs.com

GSR