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OOI Regional Cabled Array acquisition report

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1 Introduction

The Ocean Observatories Initiative (OOI) Regional Cabled Array (RCA) off the coast of central Oregon with a landing station at Pacific City was shut down from November 1 to 5, 2021 for maintenance. Silixa was contracted by the University of Washington to acquire distributed acoustic and temperature sensor data on two dark (unused) optical fibers contained in two of the OOI RCA cables during this time. The goal of this data acquisition was to achieve a rich offshore DAS dataset to be shared in the public domain. Ocean Observing Systems Security Group (OOSSG) oversaw data collection and delivery. Silixa operated an iDASv3 distributed acoustic sensor (DAS) with selectable gauge lengths of 0.25, 2, 10 and 30 meters and capable of maximum 100 kHz temporal sampling and minimum 0.25 meter spatial sampling. Additionally, Silixa acquired distributed temperature data operating a Silixa ULTIMA SM distributed temperature sensor (DTS) designed to be used with single-mode optical fiber and having minimum 1 m spatial and 1 s temporal sampling.

Silixa instruments were configured and operated by Dr. David Podrasky, Senior Geophysicist, and Noah Clayton, Field Engineer, of Silixa's Environmental and Infrastructure business unit operating from Missoula, Montana.

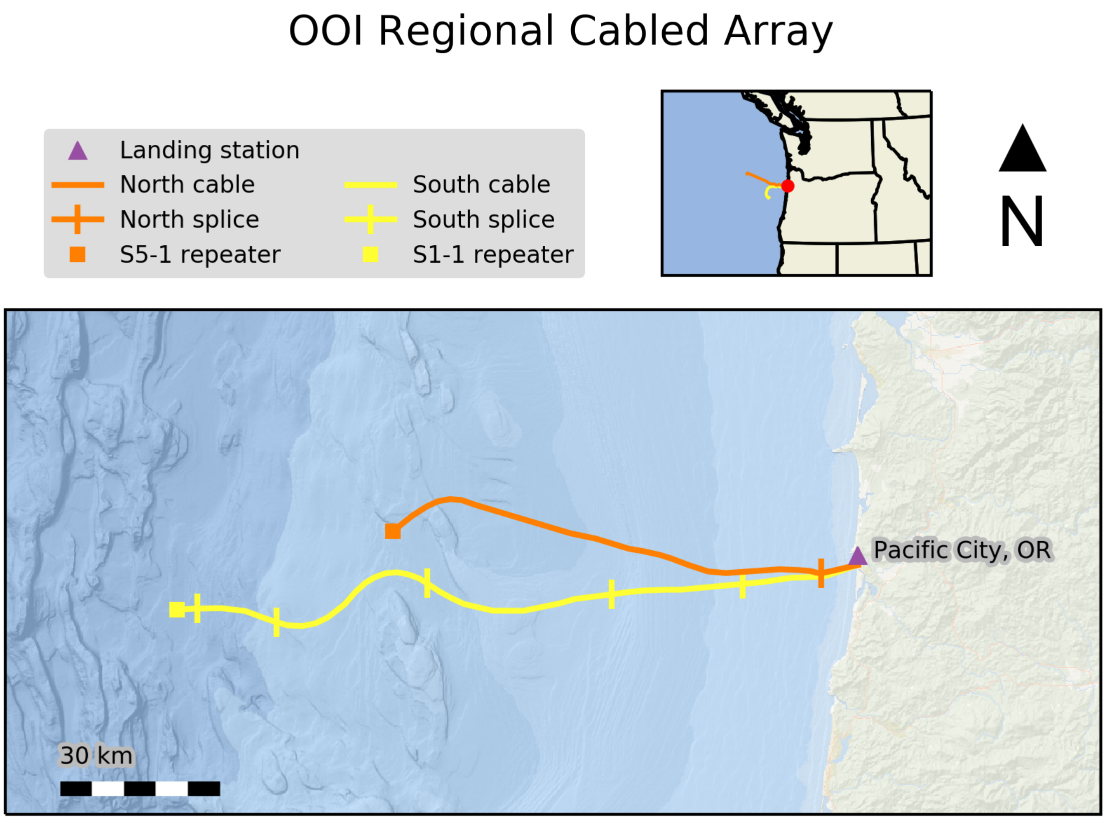

Figure 1: OOI Regional Cabled Array North and South cables. Both cables are landed in Pacific City, OR.

2 Technological overview

2.1 DAS

Operating principle

The intelligent Distributed Acoustic Sensor (iDAS) makes it possible to create a digital record of acoustic signals along a continuous length of optical fiber. Figure 2 shows the principle of iDAS operation where an acoustic field interacts with the backscattered light along a continuous length of optical fiber. By analyzing the backscattered light, and measuring the time between the laser pulse being launched and the signal being received, the iDAS can measure the acoustic signal at all points along the fiber with lengths extending into tens of kilometers. The measurements along the entire length of the sensing optical fiber are time synchronized, and the system enables coherent phase and amplitude data for the acoustic signals.

Native acoustic output

iDAS systems natively measure signals proportional to strain rate. This strain rate is computed over a length of fiber equal to the gauge length of the system. In this survey the iDAS was configured with a gauge length of 2, 10 and 30 m during different data acquisition schemes. The measurement is a running average along the fiber. This means that in this survey every receiver channel outputs the strain rate averaged over the gauge length centered on that channel.

A linear conversion must be applied to the raw data to convert to strain rate-proportional values. The formula for the conversion factor, which includes acquisition sampling frequency, f_s, and gauge length, GL,

$$\frac{116}{GL}\frac{f_s}{2^{13}} \tag{1}$$

is applied to raw samples as recorded in TDMS file format.

Directional response

As a result of well-understood characteristics underlying the operation of the system, iDAS data exhibit sensitivity which is dependent on the angle of incidence of seismic energy with respect to the orientation of the fiber. In general, this is expressed as enhanced sensitivity to those seismic signals with particle motions directionally aligned with the axial direction of the sensing fiber (Hornman, 2013).

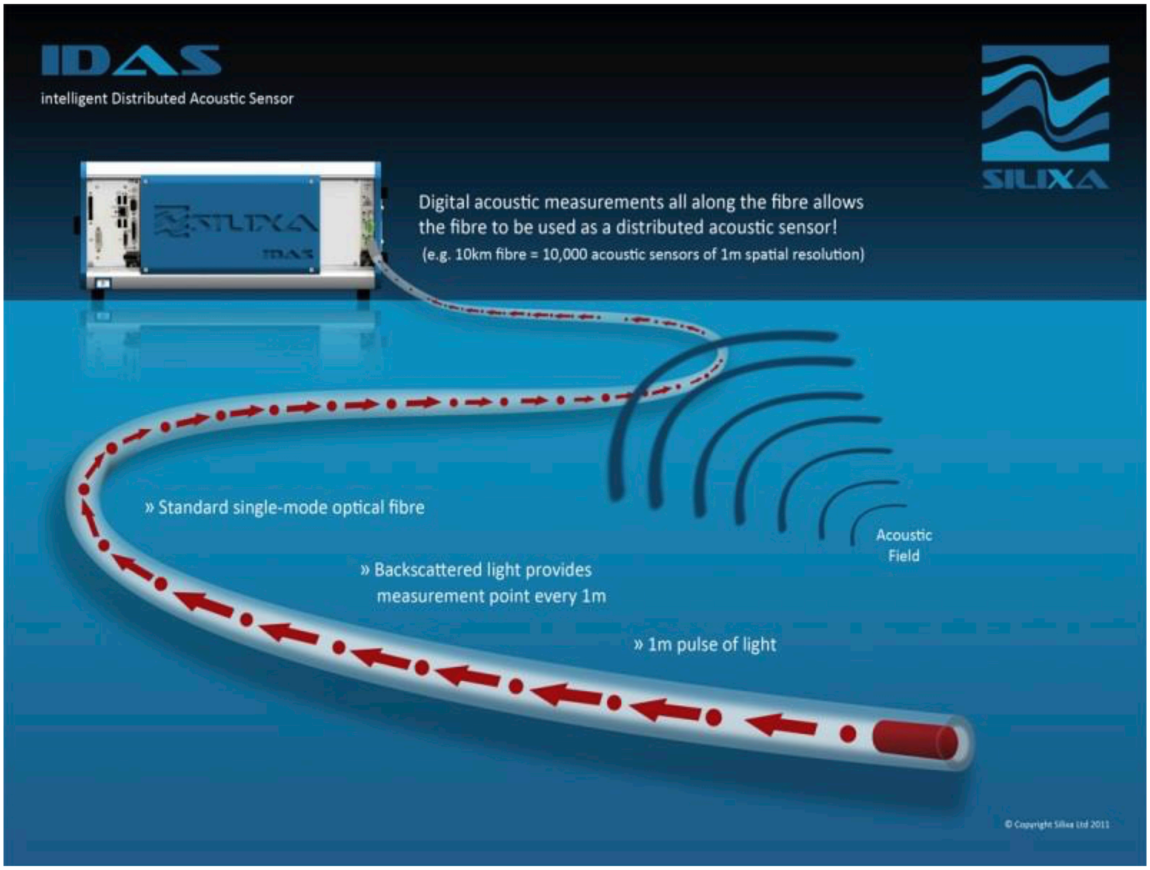

Figure 2: iDAS operational principle.

Consequently, the system tends to be less sensitive to broadside P-wave arrivals; that is, P-waves which arrive from directions perpendicular to the axial orientation of the sensing fiber.

It is important to note that this directionality in sensitivity is dependent on the component of the seismic wave arriving at a certain angle of incidence. If the angle of incidence is defined as 0° for arrivals propagating along the axial dimension of the fiber and 90° for arrivals propagating perpendicular to the fiber then this means that the sensitivity to a P-wave arrival is greatest at angles of incidence near 0°. Note that for shear waves, the greatest sensitivity occurs where the deviatoric strain imposes the maximum fiber strain. This means that the sensitivity to shear waves is greatest for angles of incidence close to 45° (or 135°).

2.2 DTS

The underlying principle of the ULTIMA DTS is a Raman-based temperature measurement combined with Optical Time-Domain Reflectometry (OTDR). A short pulse of light is launched into the fiber. The forward propagating light generates Raman backscattered light at two distinct wavelengths, from all points along the fiber. The wavelengths of the Raman backscattered light are differed to the forward propagating light and are named 'Stokes' and 'anti-Stokes'. The intensity of the Stokes and anti-Stokes light is measured, and the spatial localization of the backscattered light is determined through knowledge of the propagation speed inside the fiber.

The intensity of the Stokes light is very weakly dependent on temperature, while the intensity of the anti-Stokes light is strongly dependent on temperature. The temperature profile within the optical fiber is calculated taking the ratio of the intensity of the Stokes and the anti-Stokes detected light. A widely accepted formulation of the mathematical relation for determining temperature from the measured Stokes and anti-Stokes signals is:

$$T(z) = \frac{\gamma}{\kappa - \Delta\alpha z - ln\left(\frac{I_S(z)}{I_{aS}(z)}\right)}, \tag{2}$$

where γ depends on the distribution of quantum states and is a system constant fixed by manufacturing. γ quantifies the shift in energy between the photons travelling at the wavelength of the incident light and the backscattered Raman photons. ($\gamma = \hbar\frac{\omega}{k}$ with $\hbar$ being Planck's constant, ω is the difference in frequency between the incoming laser pulse and the backscattered Stokes radiation, and k is Boltzmann's constant.) κ is a dimensionless calibration parameter related to the temperature offset which accounts for the efficiency of the DTS components which are common factors for all the measured traces (e.g. laser optical power, efficiency of the photo-diodes converting the backscattered light into electrical signal, electronic circuits). $\Delta\alpha$ is the differential loss calibration parameter that accounts for the difference in attenuation between the Stokes and anti-Stokes signal due to their differing wavelengths. z is fiber distance. z = 0 at the DTS instrument. $I_S(z)$ and $I_{aS}(z)$ are Stokes and anti-Stokes (respectively) intenisties over distance. γ, κ and $\Delta\alpha$ must be determined through DTS system calibration in order to obtain accurate temperatures.

3 Regional Cabled Array telemetry cables

Silixa acquired DAS data on the OOI RCA fiber optic cable used for telemetry of RCA datasets. During the week of November 1, the RCA was down for scheduled maintenance allowing for a dark fiber dataset to be acquired. DAS and DTS data were collected on the transmit and receive fibers in the North and South RCA sub-sea cables. The RCA cables are equipped with optical repeater devices which disallow distributed sensing beyond the repeater. This means that the usable cable length for the North cable was 66.8 km and 97.2 km for the South cable.

The path of the two cables is shown on the maps in Figure 1. The locations of the optical repeaters and splice boxes are shown on the map. Coordinates for repeaters, splice boxes and features of interest along each cable are provided in Tables 1 and 2.

Latitude	Longitude	Cable Distance (km)	Description
45° 12.1380 N	123° 58.0290 W	2.300	Beach man hole, Pacific City
45° 12.0343 N	123° 58.7083 W	3.212	10-meter depth
45° 11.9650 N	123° 59.1620 W	3.821	Horizontal direction drill out
45° 11.9625 N	123° 59.1762 W	3.840	20-meter depth
45° 11.9218 N	123° 59.4044 W	4.149	Plow down
45° 11.5614 N	124° 1.7669 W	7.323	Splice Box
45° 11.7415 N	124° 3.4334 W	9.544	3-mile state waters limit
45° 11.7426 N	124° 7.7355 W	15.200	100-meter depth
45° 12.4509 N	124° 16.3627 W	26.786	12-mile international limit
45° 15.8597 N	124° 34.0853 W	50.904	Contiguous Zone, OR & WA
45° 14.5446 N	124° 45.0611 W	66.814	Repeater S5-1

Table 1: Positions and descriptions for features of interest along the North cable, up to the first optical repeater (S5-1).

Latitude	Longitude	Cable Distance (km)	Description
45° 12.1380 N	123° 58.0290 W	2.300	Beach man hole, Pacific City
45° 11.9854 N	123° 58.7010 W	3.226	10-meter depth
45° 11.8850 N	123° 59.1290 W	3.818	Horizontal direction drill out
45° 11.8745 N	123° 59.1670 W	3.871	20-meter depth
45° 11.8212 N	123° 59.3604 W	4.143	Plow down
45° 11.2639 N	124° 3.1513 W	9.268	3-mile state waters limit
45° 10.9097 N	124° 7.8220 W	15.441	100-meter depth
45° 10.7849 N	124° 9.7243 W	17.948	Splice box
45° 10.3752 N	124° 16.0508 W	26.285	12-mile international limit
45° 10.1436 N	124° 21.9184 W	34.009	Plow up
45° 10.0773 N	124° 22.5305 W	34.822	Plow down
45° 10.0397 N	124° 22.9803 W	35.416	Splice box
45° 8.8787 N	124° 34.2691 W	50.446	Contiguous zone, OR & WA
45° 10.8245 N	124° 41.6222 W	60.916	Splice box
45° 8.0551 N	124° 56.8581 W	83.599	Splice box
45° 9.0555 N	125° 2.4485 W	91.251	Plow up
45° 9.0499 N	125° 2.9970 W	91.974	700 fathom official boundary
45° 9.0406 N	125° 3.8853 W	93.146	End of burial
45° 9.0302 N	125° 4.8768 W	94.454	Splice box
45° 8.9228 N	125° 6.9462 W	97.218	Repeater S1-1

Table 2: Positions and descriptions for features of interest along the South cable, up to the first optical repeater (S1-1).

4 Acquisition settings

4.1 DAS

During experiment planning, prior to arrival at Pacific City, it was decided that three instrument acquisition schemes would be used for data acquisition during the week-long experiment schedule. These schemes represent an attempt at balancing the benefits of the available spatial and temporal settings against the need to maximize instrument performance on the long fiber distances between the landing station and the first repeaters on the two RCA cables.

Setting	Value	Units
Sampling frequency	200	Hz
Time Decimation	5	
Laser launch rate	1000	Hz
Spatial sampling	2	m
Measurement length	64 896 or 80 640	FD(m)
P-value	9	
Gauge length	30	m
Output decimation	1	

Table 3: iDAS acquisition settings for Scheme 1. Measurement length 64 896 m was used on the North cable and 80 640 m was used on the South cable. FD is fiber distance units.

Setting	Value	Units
Sampling frequency	200	Hz
Time Decimation	5	
Laser launch rate	1000	Hz
Spatial sampling	1	m
Measurement length	40 384	FD(m)
P-value	7	
Gauge length	10	m
Output decimation	1	

Table 4: iDAS acquisition settings for Scheme 2. FD is fiber distance units.

Setting	Value	Units
Sampling frequency	1000	Hz
Time Decimation	1	
Laser launch rate	1000	Hz
Spatial sampling	1	m
Measurement length	19 648	FD(m)
P-value	3	
Gauge length	3	m
Output decimation	2	

Table 5: iDAS acquisition settings for Scheme 3. FD is fiber distance units.

Setting	Value	Units
Sampling frequency	200	Hz
Time Decimation	5	
Laser launch rate	1000	Hz
Spatial sampling	2	m
Measurement length	80 512	FD(m)
P-value	7	
Gauge length	30	m
Output decimation	1	

Table 6: iDAS acquisition settings for Scheme 4. FD is fiber distance units.

4.2 DTS

Acquisition settings for the Ultima DTS instrument were determined during the first day of data acquisition and are listed in Table 7. Once finalized, these settings were used for the duration of DTS data acquisition.

Setting	Value	Units
Spatial sampling	1	m
Integration time	900	s
Measure length	30400	m
Differential attenuation	0.03	dB/km
Temperature offset	0.0	K

Table 7: Ultima acquisition settings.

5 Acquisition schedule

Time periods across which each of the four DAS acquisition schemes wer employed are displayed in Figure 3. Precise start/stop times are listed in Tables 8 and 9.

Begin acquisition	End acquisition	Cable/Fiber	Acquisition scheme
Nov. 01 2021 15:44:51	Nov. 01 2021 17:31:51	North/RX	Scheme 1
Nov. 01 2021 17:47:40	Nov. 03 2021 15:26:10	South/RX	Scheme 1
Nov. 03 2021 15:46:44	Nov. 04 2021 17:13:44	South/RX	Scheme 2
Nov. 04 2021 17:25:19	Nov. 05 2021 14:06:19	South/RX	Scheme 3
Nov. 05 2021 14:21:54	Nov. 05 2021 17:05:39	South/TX	Scheme 4

Table 8: iDAS acquisition schedule. All times in UTC.

Begin acquisition	End acquisition	Cable/Fiber	Acquisition scheme
Nov. 01 2021 19:18:52	Nov. 01 2021 20:19:01	South/RX	see Table 7
Nov. 01 2021 20:31:47	Nov. 05 2021 16:51:18	North/RX	see Table 7

Table 9: Ultima DTS acquisition schedule. All times in UTC.

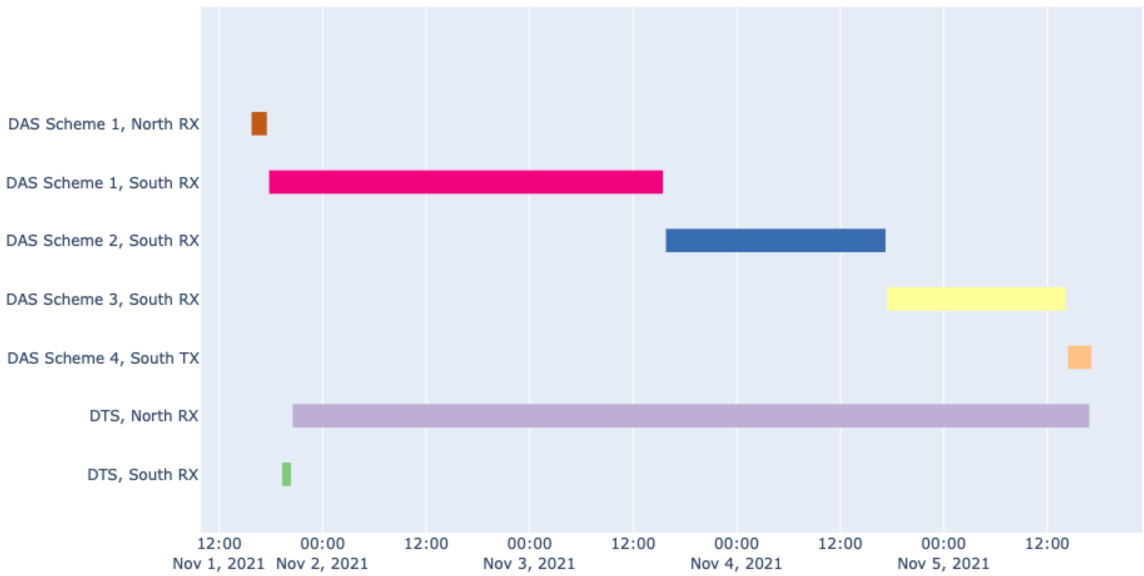

Figure 3: Acquisition schedule for DAS and DTS instruments. Settings for DAS acquisition schemes 1–4 are provided in Tables 3–6. All times in UTC.