DISCLAIMER:

DTS/DAS Logging

Project: Leak Monitoring Campaign / Carina Field Test
Client: PTAC

Client Representative:	Jason Sooley	Engineer 1:	Ben Wygal
Site Location:	Wildmere, AB, Canada	Engineer 2:	Guillermo Raya
Date:	2017/11/23 – 2017/11/24	Engineer 3:	Venkat Sundaram
		Engineer 4:	Mark Padberg (Petrospec)

Change Log:

Action	Date	Person
Submitted Well 2 Results to client	2017-12-08	Ben Wygal
Finalized Full Report	2017-12-12	Ben Wygal
Approved	2017-12-12	Pete Richter

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1. Executive Summary

Distributed fiber optic sensing offers several benefits over conventional technologies for well integrity and production monitoring. Continuous acquisition from all points along the instrumented well path means that events and features can be captured without the need to place point sensors at the right depth at a specific time. This allows the whole well to be logged simultaneously, allowing for events to be verified over an extended period of time (repeatability). It also permits the stacking of data to enhance the response of continuous phenomena. Finally, it allows for the detection of intermittent phenomena that may be missed during time-sensitive methods of acquisition (e.g. wireline).

Given its nature as a measurement along the entire wellbore and its track record for production monitoring, the same principle can be applied to leak monitoring behind casing. With the expected 20dB increase in sensitivity in the new Carina™ Sensing System, the DAS technology should be a suitable candidate for detecting gas behind casing in abandoned wells.

To this end, two wells were logged during this campaign for client. In general, the results from the two wells were good with both temperature and acoustic responses pointing to potential leaks and/or gas movement at the depths listed in the table below. For detailed results, please consult Section 6.

Well Name	PBTD	Average SCVF*	Log Date	Noise and Temperature Signature Depths**
Well 1	574m	1.76 m^3/day	23-Nov-2017	**DTS:** 272m, 343m, 429m, 560m **DAS†:** 229m, 299m, 310m, 336m
Well 2	547m	17.5 m^3/day	24-Nov-2017	**DTS:** 297m, 400m **DAS†:** 297m, 337m, 406m

*Data taken from the most recent VentMeter™ Vent Test performed in September 2017.

**All DAS/DTS depths are with reference to meters Kelly Bushing (mKB).

†All DAS data results shown were recorded with the Carina™ Sensing System.

2. Technology Overview

2.1 Operating Principle

The intelligent Distributed Acoustic Sensor (iDAS) makes it possible to digitally record the acoustic signals at every location along a continuous length of standard optical fiber. Figure 1 shows the principle of iDAS operation where an acoustic field interacts with the backscattered light generated 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.

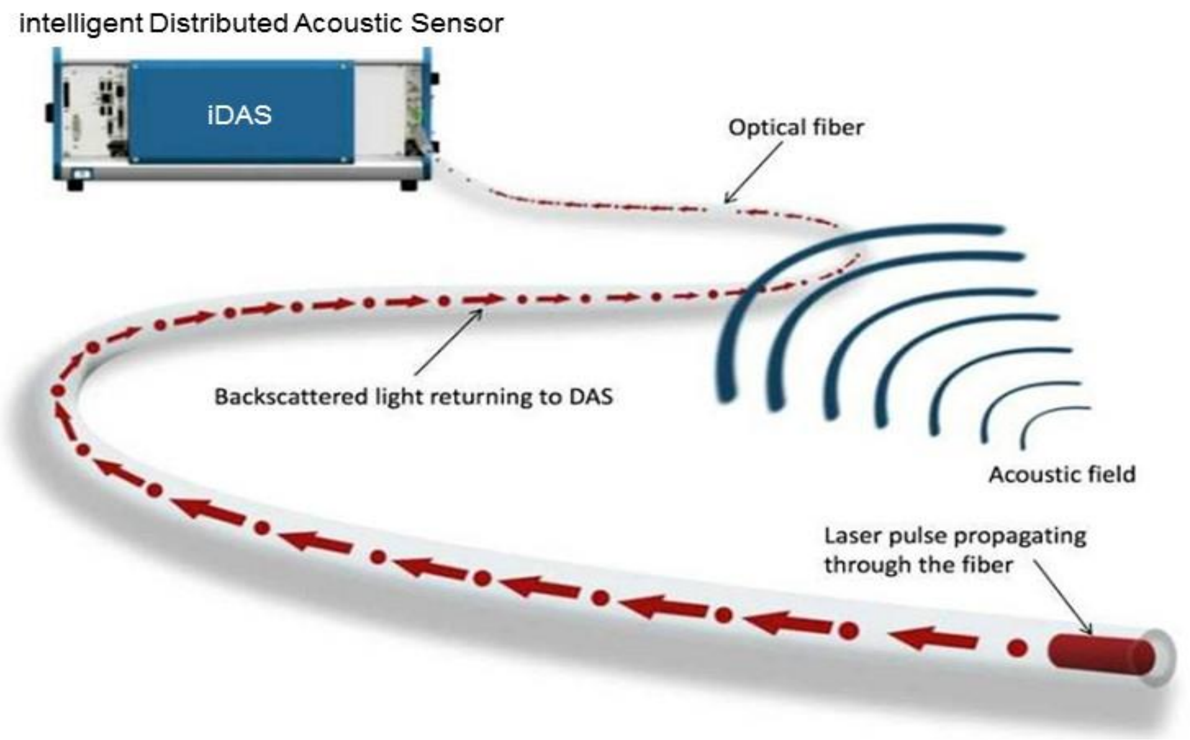


Figure 1 Principle of operation of the intelligent Distributed Acoustic Sensor (iDAS)

A key differentiating feature of Silixa's iDAS is the ability to perform measurements equally well on both single-mode fiber and multi-mode fiber, this allows Silixa to retro-fit an iDAS to existing multimode fiber installation or to utilize DTS multimode cables to perform the full scope of iDAS services.

Silixa's iDAS is a true acoustic sensor because it reproduces sound faithfully in phase, frequency and amplitude. This capability is critical for the advanced processing techniques used in several iDAS applications.

Expanding on the previous DAS generation's success, the new Carina system employs improved internal electronics and makes use of a special single-mode Constellation fiber which enhances the amount of backscattered light. Laboratory tests indicate the Carina system with this new fiber improves signal-to-noise ratio a hundredfold over the old system.

In this particular trial, a high resolution sub which consisted of 100 meters of fiber wrapped around a six foot long tube was run at the bottom of the wireline. The sub was planned to be used to observe a particular section of the well offering higher resolution and better depth accuracy. The attenuation losses for this particular fiber's wraps proved to be too great to utilize the sub while it was downhole.

2.2 Distributed Temperature Surveys

The Ultima-M DTS system uses multimode fibers to measure temperature along distances up to 5 meters. The spatial resolution was 1 meter for the first well and 0.5 meter for the second well

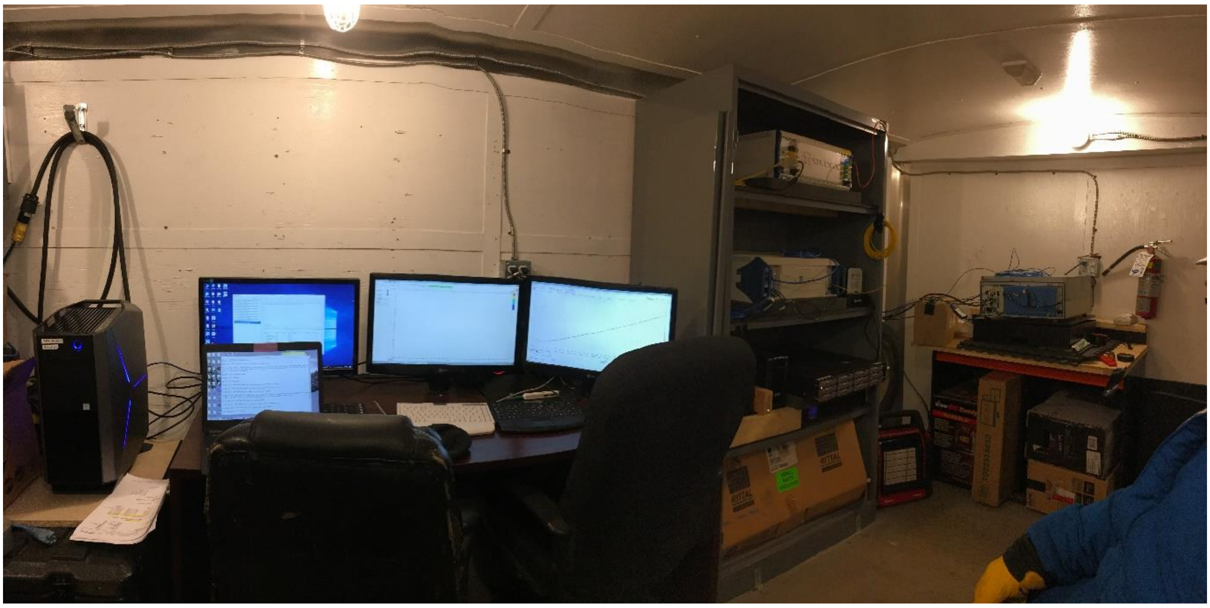
3. Acquisition Setup

3.1 Pre-Job Equipment Checks

Prior to shipment, all necessary equipment checks were made as per Silixa's standardized equipment checklists in Houston. In Canada, the Silixa engineers first checked the physical state of all equipment upon arrival at the Petrospec office. The equipment was tested on the wireline cable while it was spooled. These sample readings confirmed the system was performing within specifications. The DTS differential loss coefficient which corrects for temperature effects along the fiber was determined while the fiber was on the drum. This was performed by matching the signal determined with the coefficient versus the response given with a thermocouple positioned near the spooled cable.

3.2 Hardware/Equipment Setup

The iDAS v2, Ultima-M, and RAID were installed in a rack with foam anti-vibration padding. The associated keyboards, mice and monitors were installed on a desk in the trailer for both wells which also served as the main workstation for the engineers during the logging. The iDAS-v3 being more sensitive to vibrations was positioned on an anti-vibration table on a table away from the main congregation of people. All of the equipment was run off a series of UPS in case of power failure. All acquisition equipment listed above was run off a dedicated fit-for-purpose generator. A heater was used with its on power source to warm the cabin. Prior to starting any of the surface equipment, the cabin had to be heated to a sufficient temperature to avoid any equipment damage due to cold shock.



3.3 Network Setup

All the interrogator boxes and processing desktop were connected via the use of a Gigabit Ethernet switch for the purpose of communicating between the processing machine and the acquisition units during the job. The processing unit was utilized to process sections of the data in near real-time to pinpoint a downhole noise to then be able to allow us to move the high res sub to that depth for further investigation.

3.4 Fiber Deployment

A 1400 m spool of wireline containing a FIMT (Fiber In Metal Tube) was conveyed into each well using a spooler with a sheave wheel hung from a picker. The wireline contained three single-mode, two multi-mode, and one single-mode constellation fiber. The wireline was terminated at surface into a junction box attached to the side of the drum. Once at TD, three separate 10m pigtails ran from the junction box to the interrogator boxes inside the trailer. A special surface fiber was used for the Carina system to minimize vibrations. The cable was clamped off just above the packoff allowing the cable to be locked in place so that the upper sheave could be lowered and the tension released on the cable. The cable was then secured to nearby structures so that wind would not create vibrations into the fiber.

3.5 Software Setup

DTS was monitored using standard temperature visual outputs within both the DTS software and Distributed Data Processing (DDP). For the iDAS v2 and v3, the data was monitored using acoustic waterfall plots in the iDAS Data Acquisition software. At some points during the survey, the v3 was monitored using DDP via the processing desktop to see if possible leak locations could be spotted near real-time.

4. Results

4.1 Log Description

The log is split into four tracks as follows:

• Track 1: Wireline Logs

➢ Gamma Ray (GR, green) – measurement of natural gamma radiation

➢ Radial Cement Bond Log Maximum during 0MPa Static Pressure (AMPMAX, red) – largest amplitude observed of the 8 sample radial measurements during static pressure

➢ Radial Cement Bond Log Maximum during 7MPa Pressure Pass (AMPMAX, blue) – largest amplitude observed of the 8 sample radial measurements during pressure pass
*Only relevant to the first well

• Track 2: Frequency Spectrum

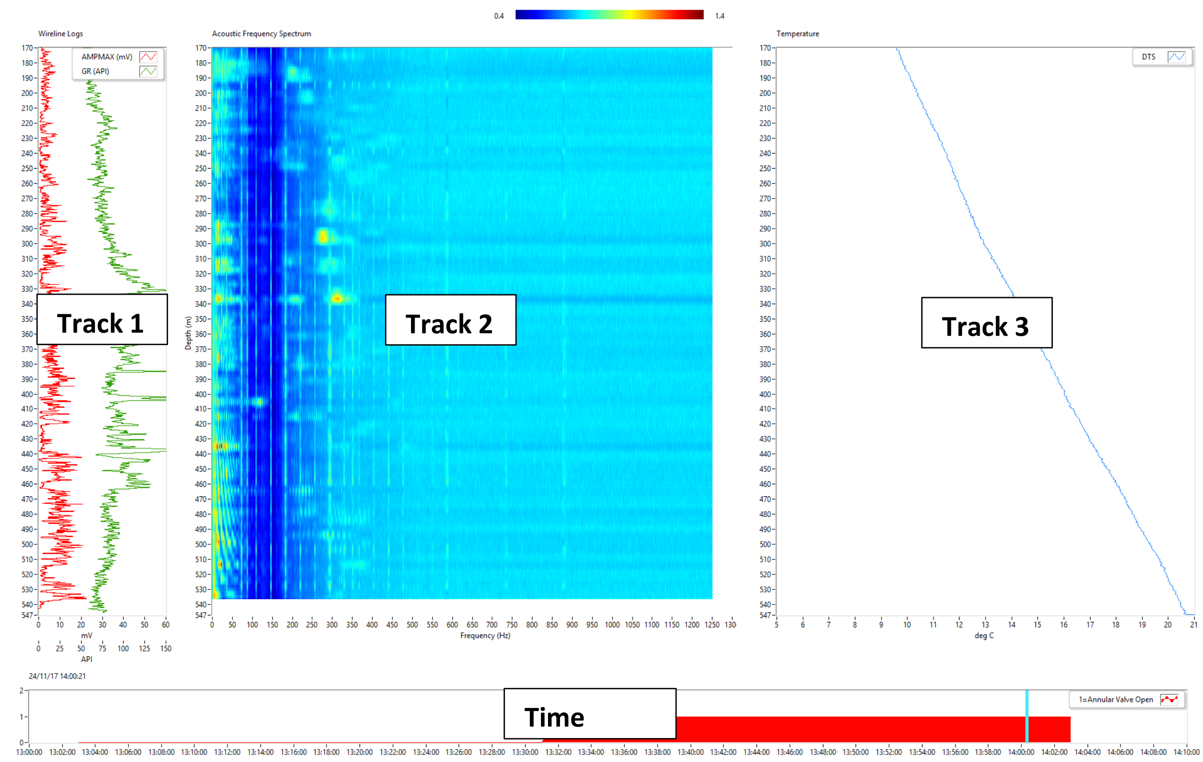
➢ Fast Fourier Transform of acoustic data processed as defined in Section 5.

• Track 3: Temperature

➢ DTS Trace (blue) – distributed temperature survey in degrees Celsius

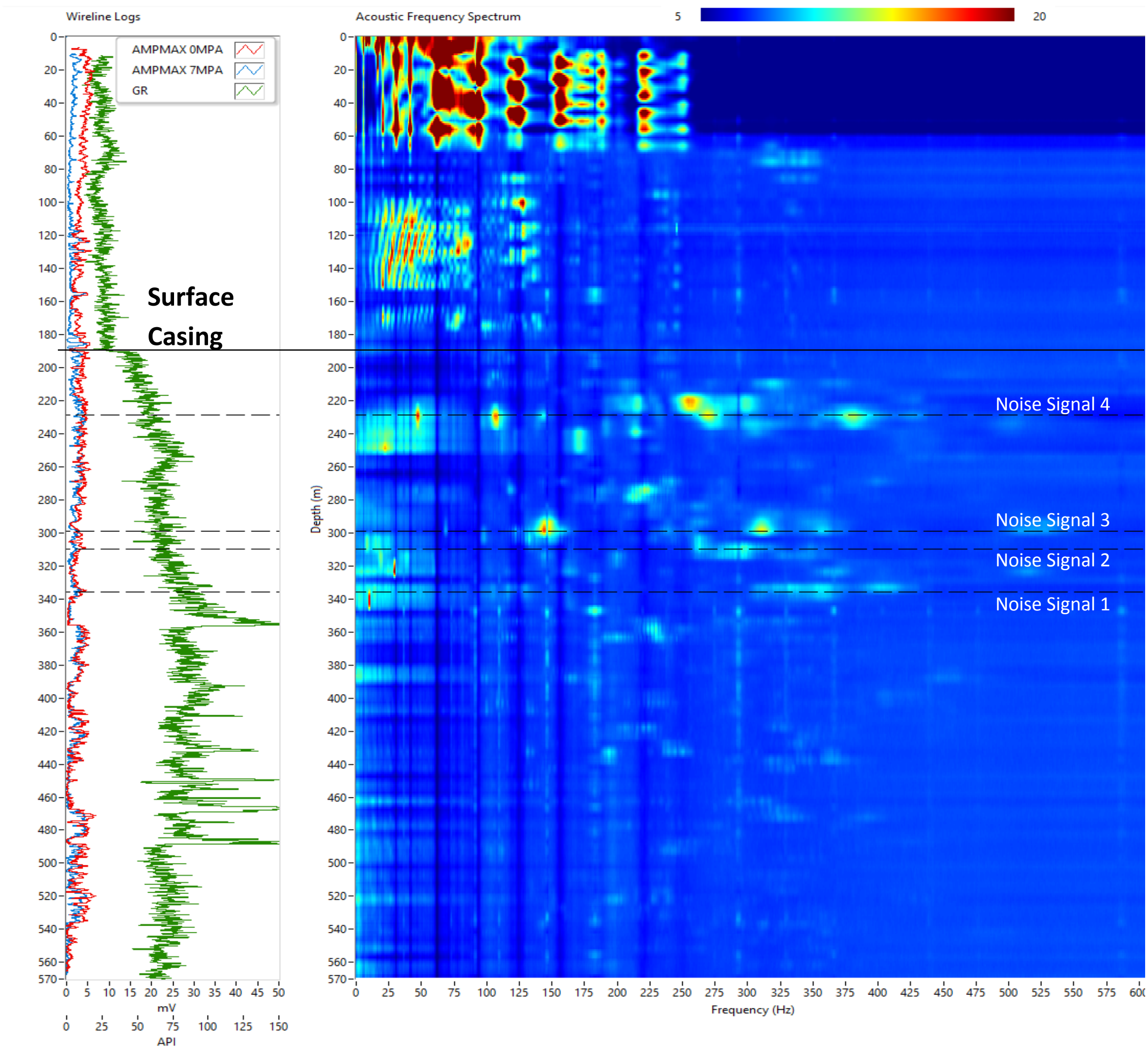
• Time Track: Vent Status

➢ Shows open/closed status of annular vent



4.2 Well 1:

Well 1 had a small amount of annular gas discharged per day so changes during our pressure buildup/release cycle were not as evident. The entire recording interval (~3 hours) was stacked in order to allow the dominant frequencies to be more apparent. We saw a large amount of noise in the top 70 meters of the well and we also saw lower frequency noise content extending down to the surface casing shoe at 190 meters. In spite of this surface induced noise in the top section of the well, four depths appeared to display a discrete noise signal as indicated below by the black dashed lines passing through the center of each signal at 229 m, 299m, 310m, and 336m. These signals are indicative of gas leaking from the formation or gas traveling up the annulus. A greater confidence is placed on the two shallower signals (229m and 299m) than the two deeper signals (310m and 336m) as the higher two have a greater intensity.



The log on the subsequent page is a snapshot in time after the annular valve was opened. The log allows comparison between the acoustic signals and the temperature trace. The acoustic signals have been circled on the Acoustic Frequency Plot and observed inflections in the DTS signal have been extended with a dashed line. The DTS presented four inflection points at 272m, 343m, 429m, and 560 m.

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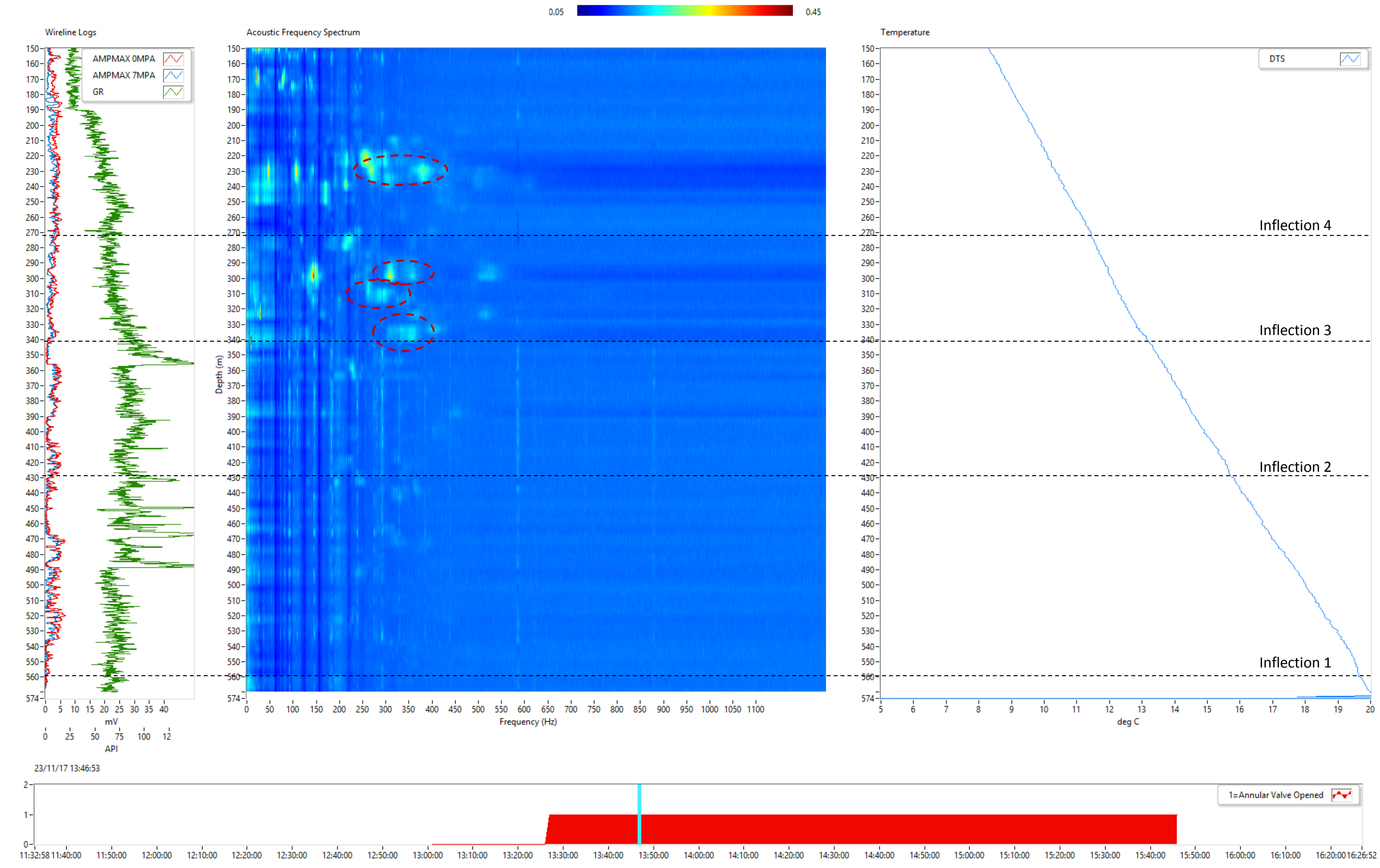
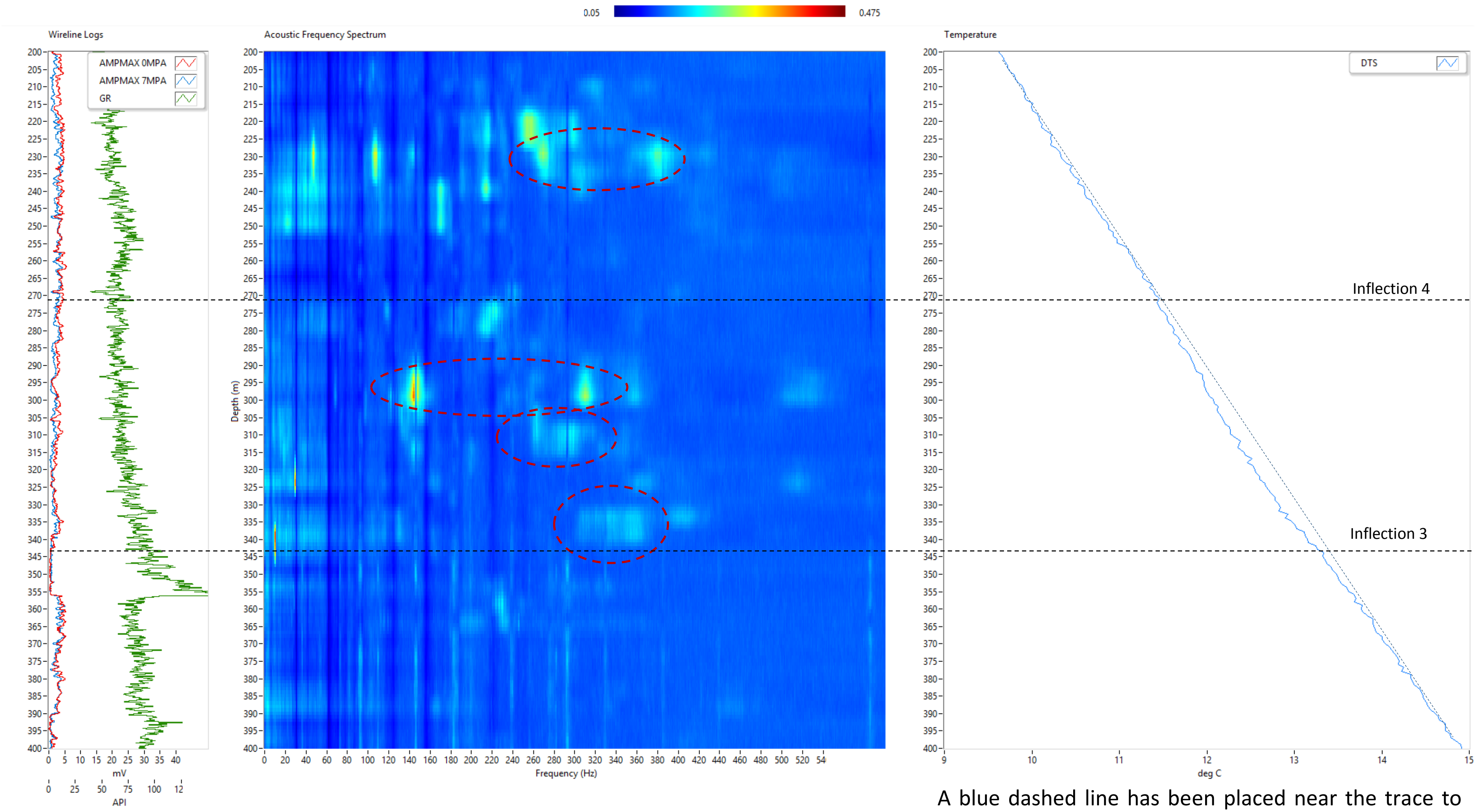


Leak Monitoring Campaign

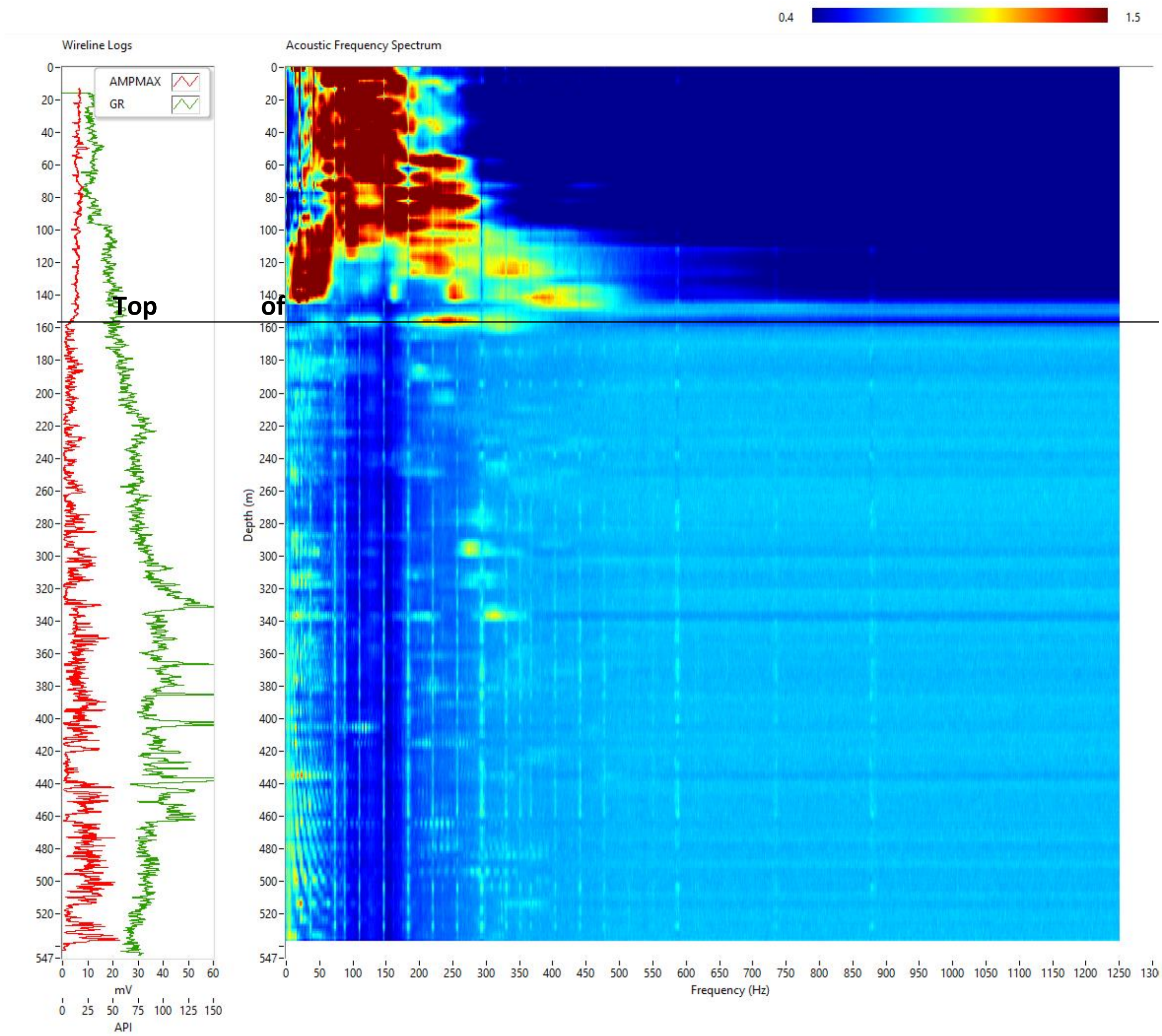


A zoomed in view of the acoustic frequency spectrum shows the most intense part of the signals are positioned at 229 m, 299 m, 310m, and 336m. A greater confidence is placed on the two shallower signals (229 m and 299 m) as there is a more intense response at distinct frequencies. The signals near 0 Hz and the vertical lines present throughout the spectrum are artefacts from the processing.

A blue dashed line has been placed near the trace to highlight the inflection points observed at Inflection 4 (272m) and Inflection 3 (343m). Inflection point 3 had the strongest response and lies near the deepest acoustic signature.

4.3 Well 2:

Well 2 had the greater volumetric release of the two wells logged. We saw a larger amount of noise at the top of the well. As can be seen from the Radial Bond Log (RBL), there is essentially free pipe above 160m which is where the noise extends down to. This contributes to the surface noise in two ways: 1) Noise is transmitted down the pipe from surface with very little attenuation and 2) Gas entry from below expanding in the annulus. Limiting the impact of this large noise feature required a bit more time on the processing side. This section was cropped out to allow better investigation of the downhole area as well.



The log on the subsequent page is a snapshot in time after the annular valve was opened. Three acoustic signals have been circled on the Acoustic Frequency Plot which may be indicative of gas leaking from the formation or gas traveling up the annulus. There is more leak indication in the two shallower signals (297 m and 337 m) than the deeper signal at 406 m as the higher two have a greater intensity. All three of these signals intensified after the valve was opened and also occur where there is a higher RBL AMPMAX. The DTS presented two inflection points at 297 m and 400 m which coincide either on or near two of the acoustic signals.

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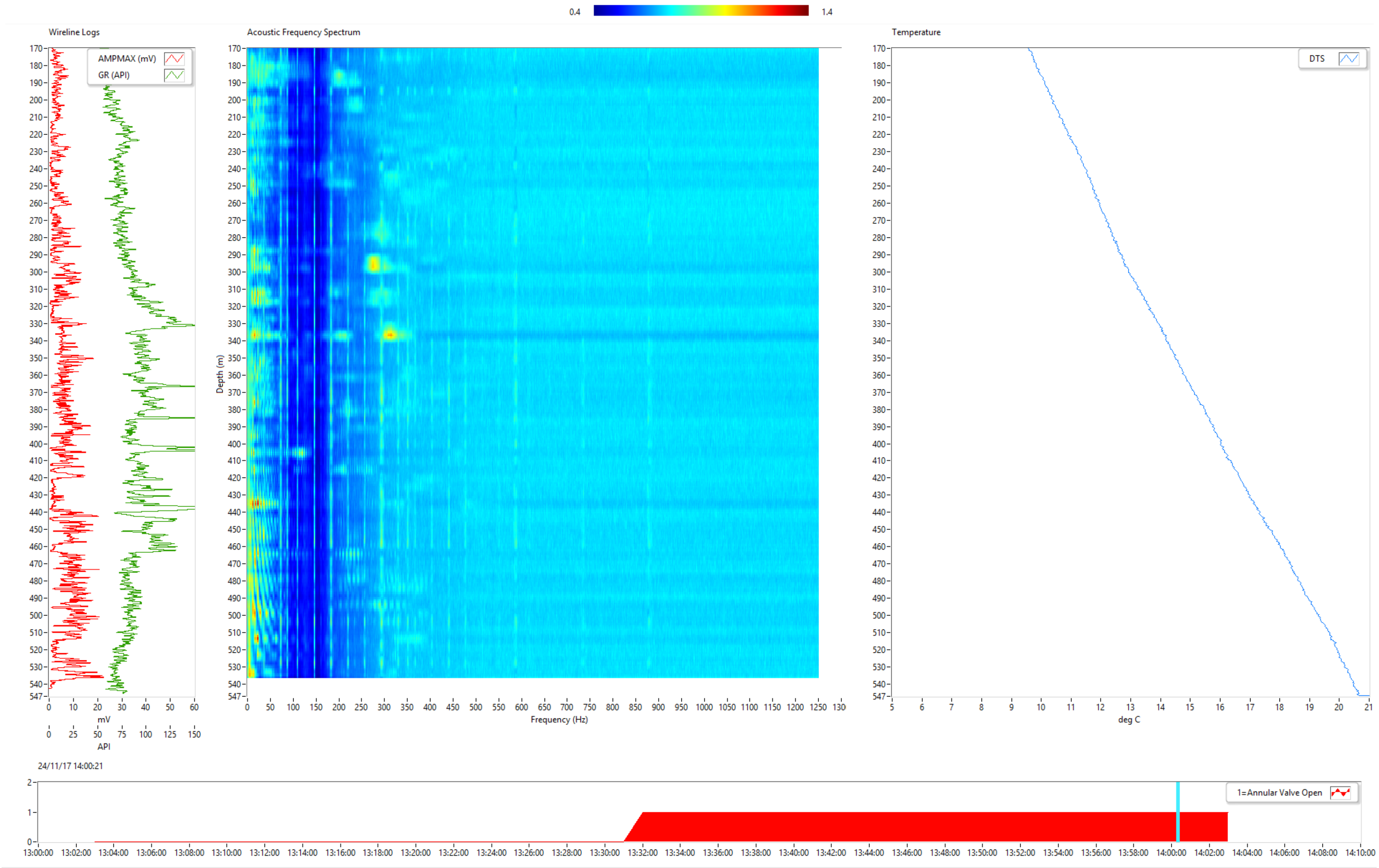

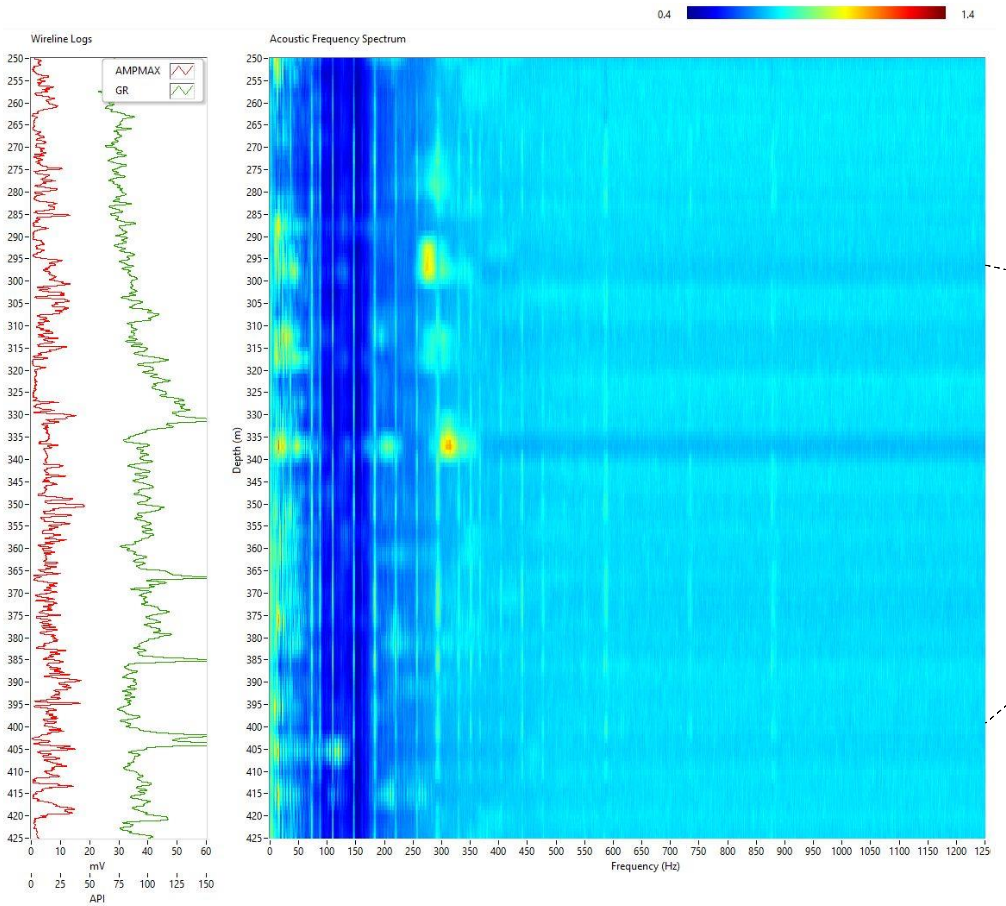

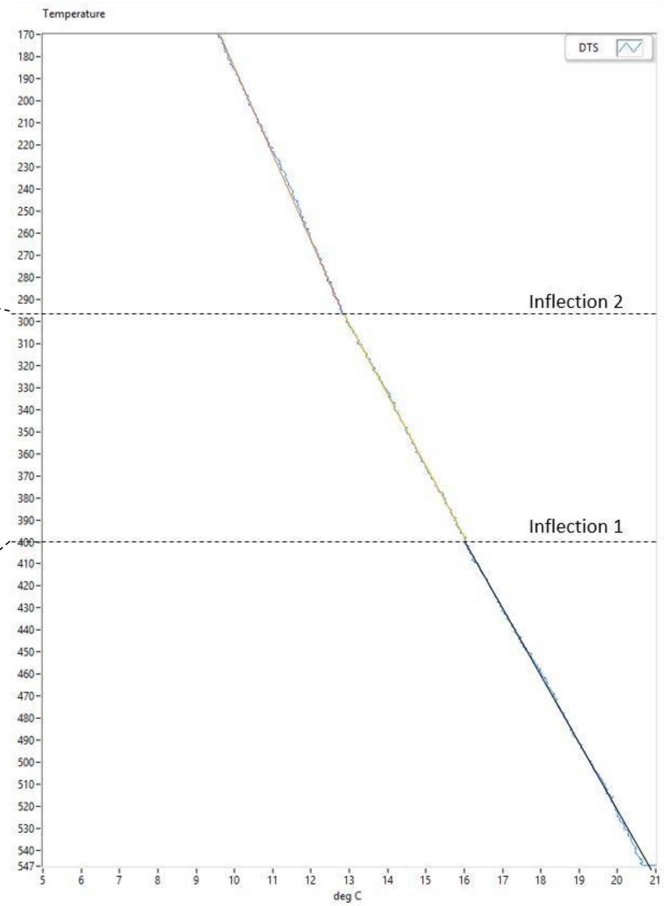

A zoomed in view of the acoustic frequency spectrum shows the most intense part of the signals are positioned at 297 m, 337 m, and 406 m. A greater confidence is placed on the two shallower signals (297 m and 337 m) as there is a more intense response. The signals near 0 Hz and the vertical lines present throughout the spectrum are artefacts from the processing.

Colored straight lines were placed over the DTS trace to identify the inflections. Where the color changes is where there was an inflection point. Inflection 2 at 297 m was a stronger response than Inflection 1 at 400m. Note: the temperature plot is not on the same depth scale as the acoustic frequency spectrum so the dashed lines were extended over to the acoustic