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Acquisition of an Ultra High Density 3d Seismic Survey Using New Nimble Nodes, Onshore Abu Dhabi

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Abstract

The benefits of using autonomous nodes in a desert environment to efficiently achieve very high trace density seismic surveys with reduced HSSE risk and improved operational efficiency are increasingly being recognised by the industry. ADNOC, in partnership with BP, Rosneft and WesternGeco recently deployed 50,000 newly-developed ultra-light nodes ([Manning et al, 2018](#)) with simultaneous vibroseis source technology to acquire the densest ever seismic survey on land. The survey covered an area of 81km² containing significant surface infrastructure and sand dunes.

The field trial had two main goals: first demonstrate the readiness of this new nodal system to acquire high quality seismic at full scale in a production-like setting; and second, to compare the data recorded by this new system to legacy data acquired by a conventional array geophone system and demonstrate the benefits of the former in terms of safety, operational efficiency and ability to image fine stratigraphic details at the reservoir.

Introduction

BP, Rosneft and WG have developed a new low-footprint seismic recording system based on the smallest and lightest seismic node available in the industry. The system proved to be more effective than existing cabled geophone systems and allow users to achieve higher density surveys at lower cost and less environmental impact. Following three successful field trials in Norway, Abu Dhabi ([Ourabah et al, 2019](#)) and Russia ([Brooks et al, 2018](#)) in which the system was compared directly against its commercial peers, 42,000 additional nodes were manufactured to bring the total receiver count to 50,800 for this final field trial before commercialization. In addition to confirming the quality of the seismic data recorded by the nodes and operational efficiency, this field trial demonstrates the ability of the system to scale up to production mode and offer the very high channel count it was designed to reach.

The choice of the test site was important to achieve both ADNOC's goal of assessing the technology as a possible enabler of high-resolution reservoir imaging and the development team's goal of assessing

its readiness for commercialization. The area chosen was deliberately difficult: a 9×9km area containing significant oilfield infrastructure, 80% of which was covered by sand dunes up to 30m high.

The most recent legacy survey was dense by historical standards: 100m×50m receivers (4×12 geophone array), 200m×50m sources (4 vibrator array, 6 or 3 stacked sweeps) and identified stratigraphic features at reservoir level. However, a higher resolution of these features is required to understand the role they play in the effective development of the field.

About the nodal system

Beyond the compact nodes, this 3D field trial aimed to stress test the entire nodal recording system at full capacity, sustained over many weeks; it was therefore important to have a full setup in this field trial.

Unlike previous tests, all components this time were available and ready to be tested at full capacity, including the calibration table used to compare the sensor's system response against factory reference signature. The field camp was setup close to the survey area inside an existing oil field services encampment. The complete nodal system comprises five standard shipping containers with a standard 200kW generator for power supply (Figs 1 & 2). Three of these containers contain core units of the system (download and charging unit, cleaning unit, recording unit), the two other containers contain a workshop for the engineers and a data storage for the NAS drives. Below is the inventory of the system as used in this field trial:

- 50,855 Nodes (17% previous version & 83% latest iteration)
- 80 Initialization Devices
- 24 Handheld Navigation Devices (8 equipped with high accuracy navigation system)
- 56 backpacks
- 33 planting poles (Crews decided not to use them)
- 84 NAS drives (60TB net capacity each) – Only 44 were used for data storage
- 1,440 × 600m strings on spools
- 1 Mobile Cleaning Unit (in a 20ft standard container)
- 1 Mobile Charging & Downloading Unit (in a 20ft standard container)
- 1 Recording Truck & QAQC system (in a 20ft standard container)



Figure 1—The field camp where the field trial operation was conducted. 20-foot Containers from left to right hold respectively: the charging and harvesting unit, the cleaning unit, the data storage unit, the recording truck unit and the workshop unit. In front on the pallets we can see approximately 35,000 nodes



Figure 2—from left to right: the calibration table, the charging and downloading racks, the deployment and retrieval backpacks, a pick-up loaded with 1600 nodes and 20×600m string reels.

Survey design

To acquire this ultra-high-density 3D survey with the available inventory, the area was divided to five zippers (source overlap) with a 12.5m×12.5m carpet of receivers and a 100m×12.5m source grid acquired with a 3km crossline offset in a double parallel sided geometry (Table 1, Figure 3).

Table 1—Survey geometry table

Bu Hasa 3D parameters		
Geometry	Number of R-line	240
	Inline maximum offset	3000m
Fold of coverage	Total	10050 (full offset range) 7200 (limited offset range to 3km)
	Bin size	6.25m × 6.25m
	Nominal trace density	184 million traces/km ²
Source points -SP	Source line orientation	S-N (0°)
	Distance between SP	12.5m
	Source line spacing	100m
Receiver points -RP	Distance between RP	12.5m
	Receiver line orientation	Grid S-N (0°)
	Number of RPs per line	144
	Receiver line spacing	12.5m
	Receiver Patch	240 lines
	Number of channels (Live Patch)	34560 minimum nodes recording per VP
Vibroseis	Drive Level	75%
	Sweep length	18 seconds
	Sweep frequency	2Hz – 120Hz
	Number of vibrators per VP	1
	Vibrator pattern	Single
	Number of sweeps per VP	1

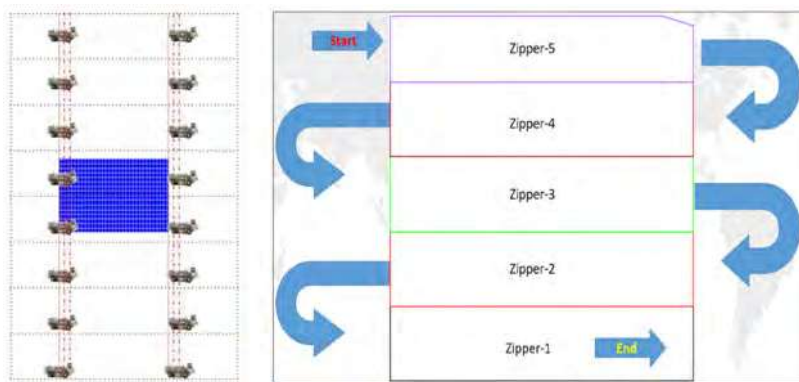


Figure 3—Double sided parallel design of the Large Scale Field Trial (LSFT).

16 vibroseis trucks worked in a semi-independent simultaneous sweeping mode and used the same sweep (18 sec, 2-120Hz non-linear sweep at 75% drive level). A time-distance separation rule was added early on during the survey to reduce the risk of vibroseis synchronization which could affect the deblending process. 8 vibroseis units were positioned on each side of the rolling spread which contained ~43,000 nodes on the ground at any given time.

Execution

Following initial mobilization and setup of the camp, line crews were provided with training in using the deployment and retrieval tools. Focus was on training the line foremen in detailed use of the deployment system followed by assisting them in training their respective teams. 36 operators were then trained and ready to use the handheld devices and backpacks for deployment and retrieval in just 2 days.

A No Surprises Test (NST) was carried out before the beginning of production to assure all equipment was performing as expected, including the interaction with the source system which was provided by the seismic acquisition contractor. A swift analysis of the combed and correlated traces from the NST showed that the system was performing well and ready for production. However, some tweaks to the planned parameters of the survey were applied after reviewing the test results, for example the start frequency of the sweep was increased from 1.5Hz to 2Hz to reduce strain on vibroseis (Figure 4) and the length of the sweep was reduced from 18s to 14 s to increase production rate.

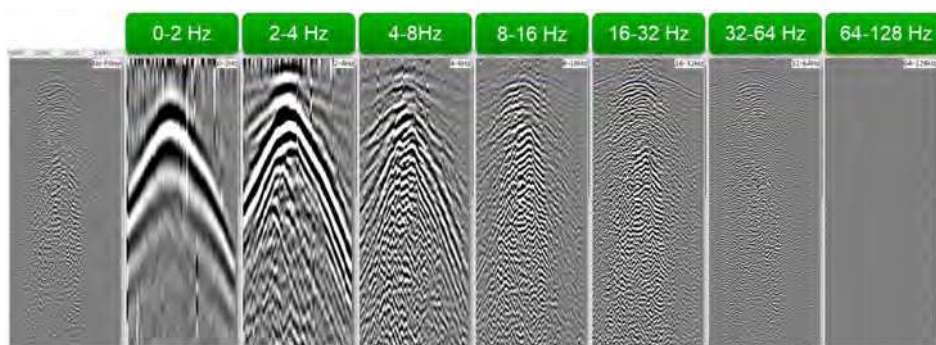


Figure 4—No Surprises Test – Seismic data from the NST filtered into frequency bands showing the node excellent low frequency response (note that the sweep used in the NST started at 1.5Hz)

Following completion of the ‘No Surprises Test’, Zipper 5 started production on March 5th with first data harvested on March 7th. The line crew demonstrated a rapid take-up of this new nodal system with 9,971 nodes deployed on day 2 of operations. The learning curve was largely complete within the first 7 days of deployment.

Both conventional deployment as well as ‘multiple deployment’ of the nodes (rolling nodes from back to front without passing by the camp for harvesting) were successfully tested during zipper 5. It was decided, however, to resume conventional deployment by rolling all nodes through the camp from the start of zipper 4 to prevent the risk of losing multiple receiver positions’ worth of data in case these nodes were too deeply buried by shifting sand dunes and became unrecoverable.

Approximately 10k nodes were retrieved each day by the back crew and returned to camp for charging and harvesting. Two junior staff operated the cleaning unit and the download & charging unit with one observer supervising and ensuring all data was harvested before sending the commands to release the nodes for next deployment. On average 10k nodes were rotated through the download & charging unit every day in less than 12 hours, with each node containing an average of 5 days’ worth of data. A day of operation in the download and charging unit varied between 6 to 10 hours in duration depending on whether the calibration table was used or not. The calibration table was used to test the integrity of the node’s sensor response by comparing the node’s response recorded at the calibration table with the reference response of the shaker. This process is quick, effective and accurate: 90 nodes can be screened in 3 minutes. Many other additional QC checks were carried out during the harvesting process to identify nodes with potential abnormal behavior. Most of them are automated and are run on the fly as the data is being recorded on disk. Any such nodes were displayed with a red cross on the user display for removal once the harvesting and download was complete. A total of 270 latest iteration nodes were flagged as potentially faulty by the end of the project: a failure rate of only 0.6%. Further analysis is being carried out on these units to identify the likely causes and the necessary modifications required to avoid future occurrences. However, it is important to note that this failure rate is already below that of many commercial nodes available on the market.

Node inventory management, including final reconciliation, was carried out during the survey using the central system’s node history database; this process was essential to keep track of the nodes life cycle in the field as well as the lost nodes. An issue that emerged early during operations after several particularly windy days was the deep burial of nodes by shifting sand dunes. Retrieval crews were unable to recover those that were too deeply buried using hand tools. Once the wind changed direction, scout teams were sent out to recover previously deeply buried nodes. A bulldozer was also used in a separate recovery effort. To reduce the number of subsequent deeply buried nodes, a decision was made to skip nodes near the very crest of the dunes as those were particularly prone to deep burial on high wind days.

Operational results

A total of about 500,000 individual node deployments were completed in 50 days, a record number of recording stations in a single survey for either BP, Rosneft or ADNOC. More than 340,000 vibrator point were shot during the survey and nodes were deployed and retrieved at an average rate of 10,000 per day (Figure 5), which made deployment and retrieval speeds equivalent. These impressive figures were achieved with a small line crew of 12 deployment teams of 3 people and 13 retrieval teams of 2 people. Crews worked to a target of 10,000 nodes per day which they have managed to achieve within only few days after the start of the operation. This target could comfortably have been raised given the impressive speed at which the nodes could be deployed and retrieved (working days were typically about 7 hours). Figure 6 shows that median deployment rates for a 12.5m receiver point interval converged to 13 seconds per station for the final 15 days of the trial and median retrieval rates started at 19 seconds per station (day 1), reached 14 seconds within the first 7 days, and converged to 12.5 seconds per station for the final 20 days of the trial. The deployment and retrieval rates were significantly better than the 2017 Abu Dhabi field trial and the 2018 Russian winter field trial.

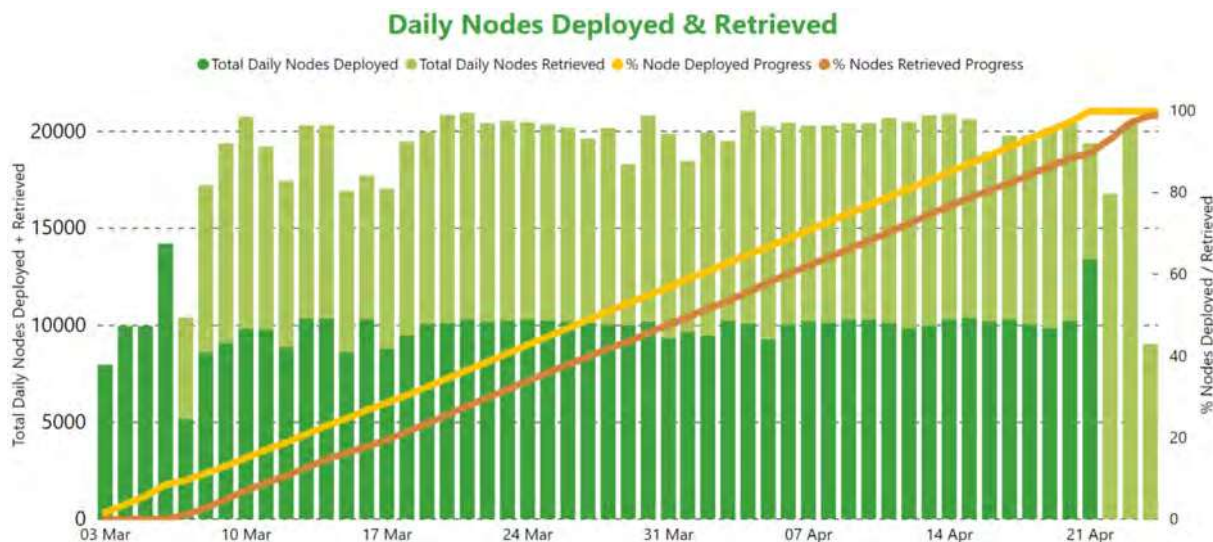


Figure 5—Daily deployment and retrieval rate. The crews achieved their target of 10,000 nodes deployed and 10,000 retrieved per day within 7 days of the start of the LSFT. We believe these numbers could increase further if the crew shifts were modified

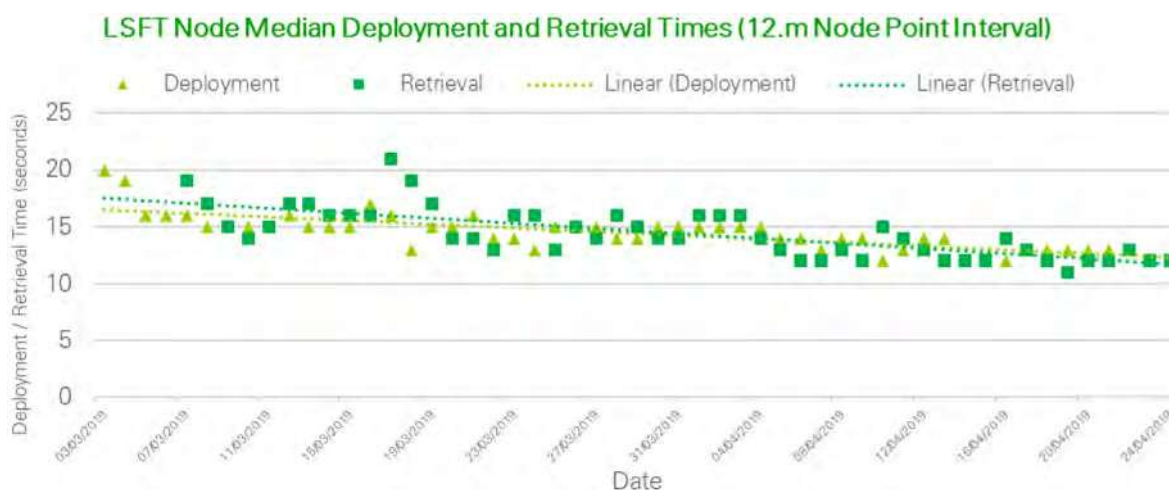


Figure 6—LSFT median deployment and retrieval time of the nodes. Here again we can see that the crews reached very quickly their "cruising speed" of 15 seconds per node. Note also that these simple manual deployment and retrieval were equivalent in time.

Analysis and Fast Track Processing

The new recording system has the capability to generate raw data as continuous records, receiver gathers and shot gathers in SEG-D format. In this field trial two copies of raw continuous records and combed and correlated receiver gathers were stored in SEG-D format on Network-attached storage (NAS) drives. As the survey was split into 5 Zippers, the data was shipped to the tape copy centre as soon as a Zipper was complete, it was then copied onto tapes and passed on to the processing centre for the fast track processing. A duplicate copy of each NAS drive stayed in the field until all tape copies were made and QC'd.

The fast track processing of this field trial was completed at the BP High Performance Computing Centre in Houston in 10 weeks. The first goal of this fast track processing was to de-risk this new nodal system ahead of commercialization; therefore, particular importance was given to the analysis of data integrity, header accuracy, auxiliary engineering data and seismic trace quality. The results of this first stage analysis have shown that the system performed as expected and all the data recorded was of excellent quality. Some comparisons between the different versions of the nodes used in this Large Scale Field Trial (LSFT) have

also confirmed that improvements in the design were performing well. The capability of the nodes to self-position to meter-level accuracy was also confirmed (e.g. [Ourabah et al, 2019](#)). In fact, as shown in [Figure 7](#), the position calculated by the node was more stable, and ultimately more accurate, than the measurements provided by the hand-held navigation devices used for the deployment which used two types of hardware, one of which was of a lesser accuracy than the other.

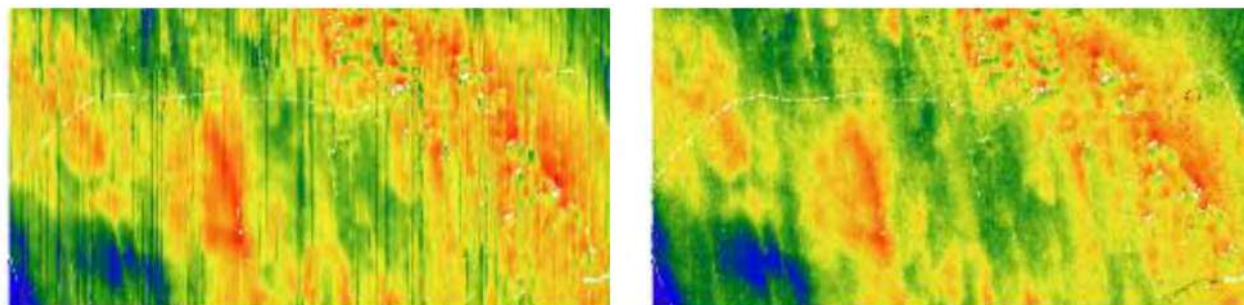


Figure 7—Surface elevation measured by handheld devices (left) compared to elevation measured by the individual nodes (right). Note the striping on the handheld device data due to different crews using two different navigation systems that had a different accuracy.

These results were encouraging and could potentially remove the need to carry sophisticated and expensive hand-held navigation devices. Subsequent to this finding, the nodes coordinates were used in the fast track processing which followed this analysis.

The fast track processing included an inversion based deblending, fast denoise, surface consistent processing and a Pre-stack Kirchhoff time Migration. Several tests were run in parallel to achieve the optimum parametrization at each stage. This parallel approach allowed us to produce a full pre-stack migrated fast track volume after only 10 weeks of receiving the last set of field data.

The project team opted for a simultaneous source approach in this acquisition not only to complete the survey in a short period of time, but also to test the system in this configuration where the source and receivers' systems work quasi-independently but still require a regular exchange of information which must be very accurate and seamlessly comprehended by each system. The first deblending of the data was tested on Zipper 5 while the acquisition was still ongoing to test the ability of the processing team to separate the shot records at the actual blending fold using an inversion-based algorithm. This has also formed an important QC step as the timing of the sources is crucial to the success of this technique.

Results of the fast deblending were very quick and separated the highly blended data well ([Figure 8](#)). A few areas revealed leakages due to extra source points outside of the nominal patch not being combed and correlated in the field receiver gathers (but still recorded in the continuous data). This leakage was easily handled with another pass of random noise attenuation in the receiver domain; however, this exercise confirmed the importance of including those extra far-offset sources in the field's combing and correlation process. It also indicated that the full processing would likely benefit from using the continuous data as an input instead of the receiver gathers to include all source points in the deblending exercise.

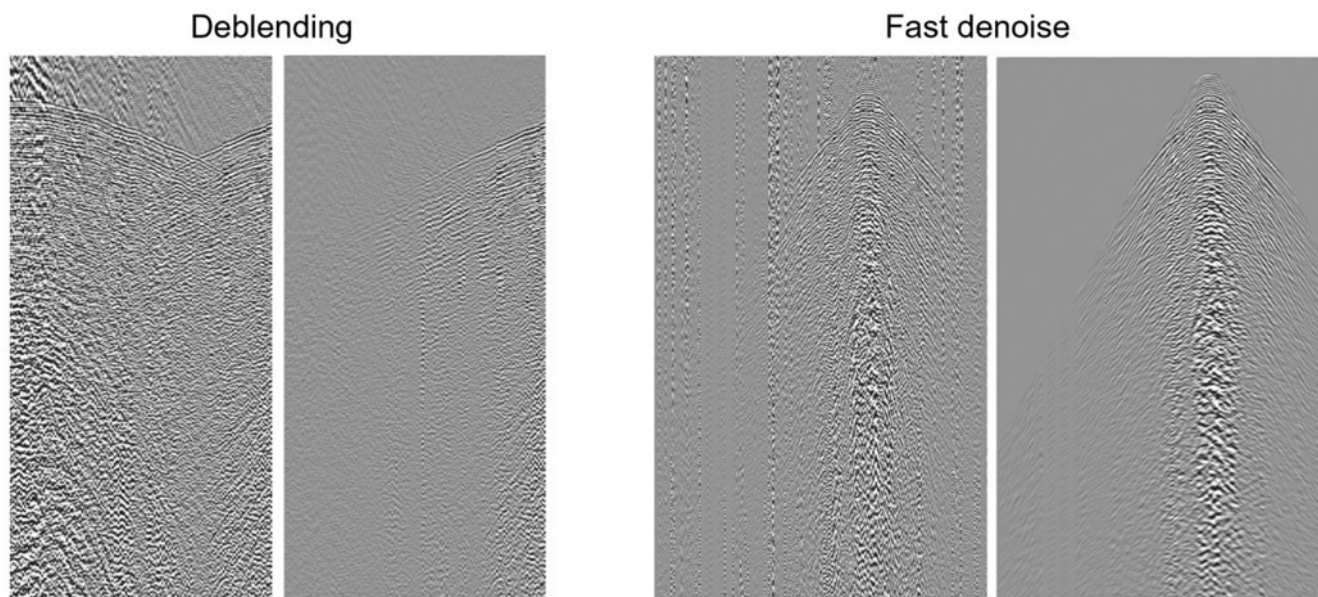


Figure 8—Two left panels show a shot gather before and after debrending using inversion-based method. the two panel to the right show receiver gathers before and after fast denoise using complex wavelet denoising (Zhou et al, 2017)

During the fast track processing, the benefit of the inversion-based debrending became very clear; in addition of being data driven and requiring very little human parametrization, it is a much more efficient process than the conventional random noise attenuation approach allowing a very swift feedback to the acquisition team.

After debrending, a fast complex wavelet denoise flow was applied (Zhou et al, 2017), this process also required very little parametrization and removed a significant amount of noise in a single step with little signal leakage. For efficiency, a parallel processing approach was undertaken where several processes were run in parallel including pre-conditioning, surface consistent processing and migrations, each delivering an incremental product, allowing the project team to have access to a minimum viable product very shortly after the end of the field trial.

It is important to note that in order to meet the tight deadline, the statics correction and the velocity field were not solved in this fast track sequence. Although an attempt to adapt the legacy statics and velocity field was applied, the changes in the near surface (movement of the dunes) made this task difficult to achieve. However, the results were sufficient to inform us about the performance of the system and the fast track volume gave the project team confidence in the ability of the system to deliver quality seismic in a production mode (Figure 9). A full production processing project has been initiated after the fast track sequence where these essential steps of land processing will be addressed properly. The relatively dense carpet of receivers should allow a good sampling of the cultural noise as well as the source generated noise which should benefit the denoise stage (Ourabah et al, 2014); this in turn, combined with the wide azimuth design, is expected to improve AVO and azimuthal attributes (Ourabah et al, 2015). The results of this full processing will be the subject of a further publication.

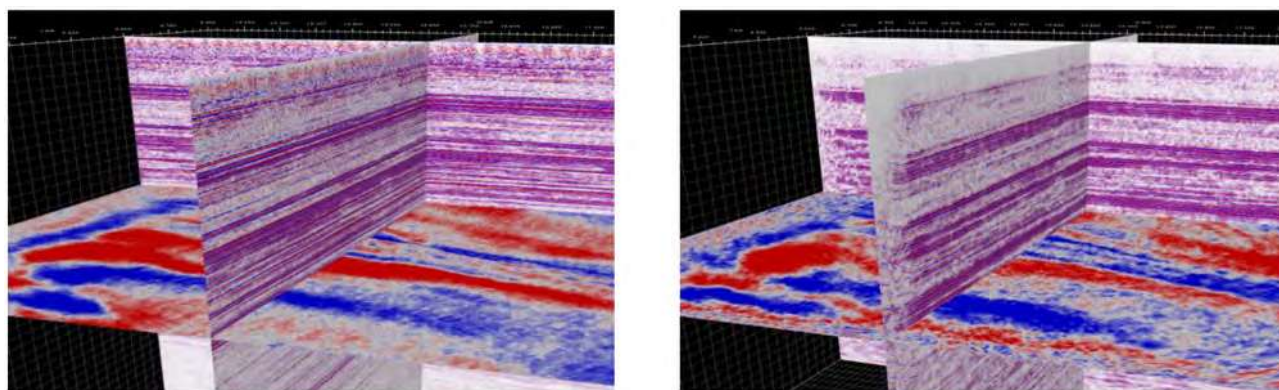


Figure 9—(Left) Time slice extracted from the legacy survey (non-blended array acquisition) achieved after 2.5 years of production processing. (Right) Time slice at a similar level from the LSFT fast track processing achieved after 10 weeks of simplified processing flow relying on data density. Despite the numerous differences in the processing sequences, velocity field, statics, phase and timeline, the similarities between the two volumes are remarkable as the fast track processing volume captures most of the features seen on the legacy.

Conclusion

The survey was acquired in 50 days with no HSSE incidents. 12 billion traces were recorded achieving a total trace density equal to 184.3 million tr/km² with a nominal fold of 7200 on a 6.25m×6.25m bin.

This new nodal system delivered outstanding operational efficiency in a challenging environment with high dunes and significant oil field infrastructure: on average, 12 teams of three people deployed 10,000 nodes per day, and 13 teams of two people retrieved 10,000 nodes the same day, typically in less than 7 hours per day in the field. As observed in previous field trials, the uptake of deployment and retrieval of equipment was very fast and required very limited training (<2 days). Crews very quickly achieved an outstanding rate of 4 stations per minute for both deployment and retrieval.

The initial assessment of the seismic data shows high quality records consistent with previous trials of this new nodal system. The fast track volume, achieved in record time (10 weeks), revealed a very informative subsurface image in alignment with the legacy data despite unresolved statics and an inaccurate velocity field; this provides us with confidence that the system delivers a high quality seismic, while the full processing is expected to achieve better results by including those essential processing steps and taking advantage of this exceptional trace density.

This is the first-time autonomous nodes have been used in such density in a desert environment. The operational efficiency of this system demonstrates cost effective high-density acquisition will be feasible over a much larger area with a much higher channel count (expected to be several hundred thousand to one million nodes). We have also successfully tested the continuous redeployment of nodes at different locations without harvesting data between successive deployments, an approach that could have a significant impact on acquisition efficiency in more difficult terrains.

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References

- Brooks, C., Ourabah, A., Crosby, A., Manning, T., Naranjo, J., Ablyazina, D., Zhuzhel, V., Holst, E., and Husom, V. 2018. 3D field trial using a new nimble node: West Siberia, Russia. *SEG Technical Program Expanded Abstracts* **2018**: pp. 6–10.

- Manning, T., Brooks, C., Ourabah, A., Crosby, A., Popham, M., Ablyazina, D., Zhuzhel, V., Holst, E., and Goujon, N. 2018. The case for a nimble node, towards a new land seismic receiver system with unlimited channels. *SEG Technical Program Expanded Abstracts* **2018**: pp. 21–25.
- Ourabah, A., Bradley J., Hance T., Kowalczyk-Kedzierska M., Grimshaw M., and Murray E. 2015. Impact of acquisition geometry on AVO/AVOA attributes quality – A decimation study onshore Jordan: 77th Conference & Exhibition, EAGE, Extended Abstracts.
- Ourabah A., Crosby A., Brooks C., Manning E., Lythgoe K., Ablyazina D., Zhuzhel V., Holst E. and Knutsen T. 2019. A comparative field trial of a new nimble node and cabled systems in a desert environment. 81st EAGE Conference and Exhibition, EAGE, Extended Abstracts.
- Ourabah, A., Grimshaw M., Keggin J., Kowalczyk-Kedzierska M., Stone J., Murray E., Cooper S., and Shaw L. 2014. Acquiring and imaging ultra high density land seismic data – Practical challenges and the impact of spatial sampling. 76th Conference & Exhibition, EAGE, Extended Abstracts
- Yu Z., Abma R., Etgen J., and Sullivan C. 2017. Attenuation of noise and simultaneous source interference using wavelet denoising. *GEOPHYSICS* **82**: V179–V190.