

# Marine Seismic Technology Workshop: Highlights and Summary

The [SEG Advances in Marine Seismic Data Acquisition Workshop](#) was held virtually on September 7-9, attracting about 80 registered participants. 24 presentations were spread over three half-day timeframes and six sessions. I summarize key elements of the workshop content below.

Topics covered included increased near-surface seismic resolution, time-lapse 3D (4D) seismic, towed streamer and ocean bottom node (OBN) sensor considerations, distributed acoustic sensor (DAS) fiber optics, reducing towed streamer survey cost by pragmatic compromises in survey design, reducing OBN survey cost with autonomous node designs, fundamentally-different approaches to spatial and/or spectral wavefield sampling, multi-source towed streamer case studies, and marine vibrator insights. Overall, it is clear that significant capital efforts are inevitably required over long timeframes to bring 'new acquisition concepts' to fruition—more so when the concepts represent a fundamental departure from traditional hardware platforms. Correspondingly, creative methods that repurpose traditional acquisition hardware and survey design templates can offer significant data improvements without necessitating expensive engineering development.

## Introduction

Workshop co-chairs were Raimon Alfaro (TotalEnergies) and Martin Widmaier (PGS), and SEG management and support was provided by Suba Jaganathan.

There is no doubt that the Covid pandemic has completely shaken up the professional societies used to generating income from a multitude of live gatherings each year. For example, struggling for relevance, the SEG and AAPG societies agreed to merge their annual US-based events into an 'IMAGE' conference for the next five years. Time will tell how much further change is necessary in the professional society models to ensure their survival.

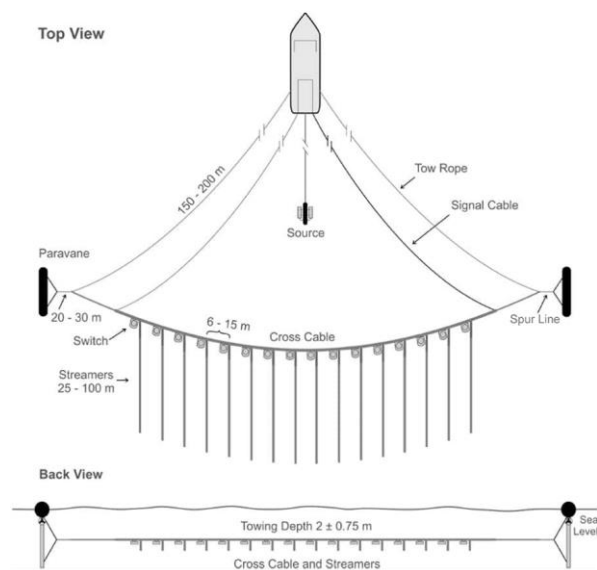
On a positive note, the SEG workshop event showcased how pre-recorded presentations can improve the quality and consistency of technical presentations from speakers of all nationalities and backgrounds; many of whom may not use English as their first language. This was partly evident during virtual conferences in 2020, but the chairpersons too often failed to manage the challenges of engaging both live and virtual event attendees in 'hybrid' events, and often wherein local bandwidth and latency challenges could make life difficult for virtual participants. No such problems were evident at the SEG workshop, and the chairpersons all managed the virtual landscape admirably. One has to wonder whether this is the new 'normal', even if the world manages to overcome Covid: for cost and other reasons of practicality, most events will continue to be managed as virtual forums.

A keynote by Sandeep Chandola of Petronas titled 'A Journey of Advancement & Innovation in Marine seismic Data Acquisition' showcased a decade-long \$1b investment by Petronas in the evaluation and application on new marine acquisition technologies, motivated by improved geophysical benefit, efficiency and HSSE. The value of partnerships with innovators and other operators with access to differentiating technology was emphasized, and the most recent technology forays involve CCS and 'new energy' initiatives across several global locations. Several elements of Sandeep's talk were addressed in more detail by other Petronas speakers during the event; including a wide-azimuth (WAZ) towed streamer case study from West Africa, marine vibrator testing from Malaysia, and a penta-source towed streamer case study from Malaysia. Multisensor OBN experiences were also highlighted, with notable benefits for converted-wave imaging in areas affected by gas clouds. The well-known dilemma of extremely high cost for OBN acquisition was also mentioned, with an expectation that judiciously-designed hybrid streamer-OBN acquisition may reduce cost by as much as 75%. Indeed, improved efficiency and lower cost was the recurrent theme throughout the workshop insights.

## Near-Surface Insights for New Energy Pursuits

The session titled 'NEW ENERGIES - HIGH RESOLUTION NEAR SURFACE SEISMIC I' was primarily concerned with increased near-surface seismic resolution for a variety of applications, including CCS, seafloor mining, and wind farm preparations.

Thibaut Choquer (Kappa: High-resolution Acquisition Solution for Cost-effective Marine Seismic Operations) and Larry Scott (NCS Subsea: P-Cable Ultrahigh Resolution (UHR) Seismic Data for Carbon Capture and Storage (CSS)) both presented similar approaches (PIKSEL and P-Cable, respectively) to the towing of short (100-450m dependent upon the number of streamers being towed, and their configuration) hydrophone-only streamers with dense receiver intervals (as small as 1.5625m) and close streamer separations (as small as 6.25m). Compact sources such as (stacked) sparker, boomer or small air gun combinations are used; and a single, longer streamer (1-1.5km) or complementary sparse OBN acquisition may be used to provide velocity model updates if a model is



not already available. Both presentations highlighted the fundamental necessity for dense spatial sampling of the receiver wavefield (e.g. 1.5625 x 3.125m natural grid) to enable the (near-surface) imaging of frequencies higher than a few hundred hertz, and the need to minimize weather downtime and other inefficiencies. There seemed to be a general belief amongst many workshop participants that traditional elastic characterization of the near-surface (i.e. Necessitating a large range of incidence angles for inversion) was not critical for understanding CCS seal integrity; and rather, the precise delineation of fracture networks and small gas seeps is of a higher priority—which the examples shown certainly showcased. Overall, these high-resolution acquisition tools were seen as an important complement to traditional marine acquisition methods, and represent part of a continuum of tools that extend to even higher resolution seafloor mapping afforded by AUV multibeam and sidescan solutions.

Figure 1. P-Cable schematic layout. Courtesy of [NCS Subsea](#).

Adriana Ramirez (TGS: Decasource offshore 3D Seismic Survey for Deep-Sea Mineral Exploration) also indicated that traditional survey design paradigms can be altered somewhat for 'new energy' pursuits. In the cases of deep-sea mineral exploration and wind farms, only the first few hundred meters below mudline is of interest, so it may be feasible to increase sail line separation to reduce survey cost (thereby sacrificing deeper seismic image quality), and still be able to satisfactorily exploit the overlapping receiver coverage to meet shallow seismic imaging requirements. The comparison shown of penta-source shooting vs. a deca-source concept based upon seismic apparition sampling, however, used traditional sail-line geometry. In the deca-source case, ten sources were achieved by only firing two half-parts of five sub-arrays of air guns, wherein all 'shots' occur within milliseconds of each other, and the [seismic apparition approach](#) to inversion-based shot reconstruction is used as an alternative to traditional deblending. The benefit of multi-source acquisition is denser receiver wavefield sampling with complementary denser inline source wavefield sampling. Overall, 12.5m subline sampling in an efficient manner is viewed as meeting the 'detectability' requirements when mapping heterogeneous distributions of seafloor massive sulphides (SMSs). Production seafloor mining may necessitate tailored acquisition solutions such as P-Cable / PIKSEL, autonomous underwater vehicles (AUVs), and complementary geophysical methods such as towed EM and borehole seismic will probably play a role in time too.

Andrew Long (PGS: Exploiting the Full Seismic Wavefield for Geohazard Quality Shallow-to Deep Resolution) reminded participants that singly-scattered reflections can be complemented in seismic imaging by multiply-scattered wavefields when multi-component towed streamer or OBN data is available. Reprocessing case studies were used to build a narrative that within the frequency bandwidth limits of emerging wide-tow multi-source acquisition with airgun sources (about 0-250 Hz), 'full-wavefield' imaging can significantly enhance near-surface seismic image resolution in a highly efficient manner. Survey designs that enable uniform and dense source line coverage as a complement to dense receiver wavefield sampling are the preferred platform looking forwards for marine seismic surveys that simultaneously deliver near-surface and traditional reservoir depth insights.

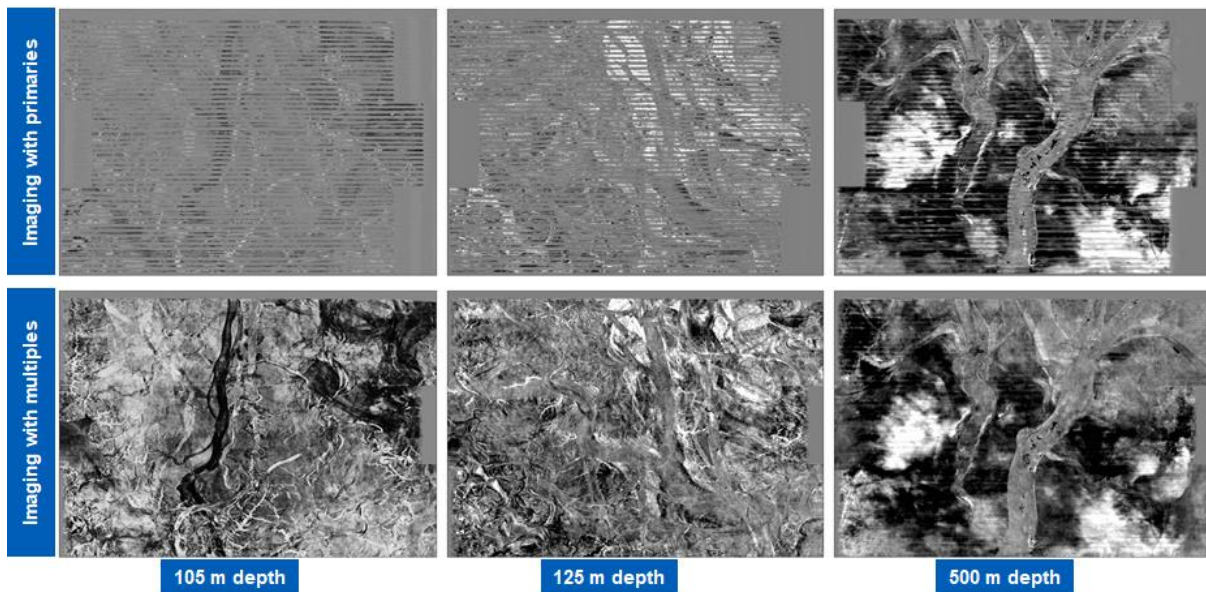


Figure 2. (upper row) Conventional Kirchhoff PSDM of multisensor GeoStreamer data in shallow water offshore Malaysia; (lower row) Separated Wavefield Imaging (SWIM) applied to the same data.

Matt Cannon (Shell) used OBN data acquired in Malaysia (also discussed later by Shell and BGP) to show how the near-field hydrophones (NFHs) distributed along traditional air gun sub-arrays can be used for high-resolution near-surface imaging (to about 500m below mudline). For a dual-source setup, the NFHs of the non-firing (i.e. passive) source array were used to record the scattered wavefield from the active source array. NFH-based images can be processed and generated in near-real time, are short-offset by nature (the source separation), can be achieved in shallow water where towed streamer operations may be impractical (although 50 m may be relatively large for 5-60 m water depth), and demonstrably contribute to the placement of safer well locations.

### Time-Lapse 3D (4D): Many Perspectives Required

The second session titled '4D (TIME LAPSE) SURVEYS' presented three quite different perspectives on an increasingly complex topic. The group discussion at the end of the first day enabled the speakers to explore the sensitivities of their workflows and methods to different survey considerations, and emphasized that the 4D journey has just begun—particularly for CCS and 'new energy' applications.

Azim Salleh (Shell: 4D Monitoring Technologies in Brunei Shallow Waters) presented three examples of 4D time-lapse surveys guiding field management in shallow water Brunei. He illustrated how to adapt acquisition platforms and processing workflows to different surface and subsurface scenarios. Pre-survey modeling focuses on VOI and business impact, and integrates as many data types as possible. A common challenge of unobstructed 4D baseline survey areas being subsequently affected by production infrastructure was addressed with examples of survey designs that integrated likely hybrid towed streamer, OBN and borehole acquisition (e.g. DAS: distributed acoustic sensing with fiber optics) into the baseline design.

Emma McDonald (ION Geo: Swath Matching Technique: An Unconventional Yet Efficient Way to Acquire 3D Seismic Surveys Offshore – A North Sea Example) introduced their swath matching approach, which uses current and streamer feathering modeling to determine the order of sail line acquisition; in contrast to traditionally acquiring all sail lines sequentially in a race-track manner. She demonstrated that their approach significantly reduced infill requirements (from 13 to 5 infill lines) and associated survey duration in a Mid North Sea 3D survey. The key metric used was Unique Bins Per Hour (UBPH) acquired. No discussion was given to implications for matching geometry in 4D monitor surveys where current and streamer feathering conditions may have changed, but the pragmatic approach was well received.

Mike Branston (Schlumberger: Designing an Objective-Based Time-Lapse Acquisition Strategy) introduced a comprehensive 4D time-lapse survey design strategy. He emphasized the importance of generating a calibrated 4D elastic rock model to create synthetic data that honors the 4D reservoir changes, showcased the flexibility and reliability of modeled Point Spread Functions (PSFs), and illustrated a hierarchical interpretation strategy to guide how to incorporate seismic data into the simulation model and history matching. PSFs are integral in some image



domain implementations of least-squares migration (LSM), and it has been shown elsewhere (e.g. PGS REF) that the diagonal of the Hessian matrix effectively computed within LSM is a flexible proxy for subsurface illumination. An elegant aspect of the modelling shown was a semi-quantitative pre-survey insight into how the recorded seismic signal can be integrated into history matching (e.g. used in terms of AVA attributes, or used in a more sophisticated manner as reservoir properties such as saturation and pressure inverted from the seismic data).

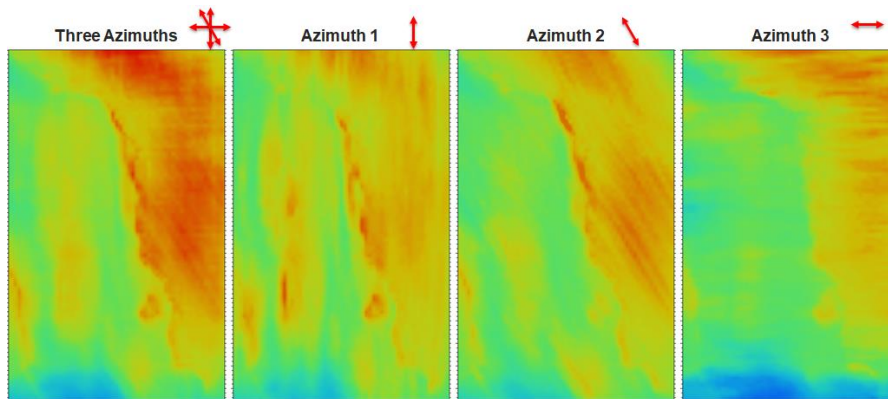


Figure 3. Example illumination modeling for a multi-azimuth (MAZ) survey in deep water. Point Spread Functions (PSFs) were explicitly computed, and the diagonal of the Hessian matrix provides a proxy for illumination. Target depth = 5600 m. Courtesy of Nizar Chemingui (PGS).

## Pragmatic Compromises and New Sensors

Day two began with the third session titled 'MARINE DATA ACQUISITION TECHNOLOGY I', and included an eclectic collection of different marine acquisition considerations.

Sergio Grion (Shearwater: Hybrid PZ Streamers) took a pragmatic approach to utilizing mixed streamer inventories of hydrophone-only and multisensor streamer sections. The most likely location for multisensor streamer sections in an otherwise hydrophone-only spread would be at the streamer fronts or for the centre streamers. Considerations was given to inversion-based deghosting of the different streamer types, with multisensor data recorded over the Forties field in the North Sea used in receiver decimation testing to simulate hydrophone-only acquisition. It was noted that the existing recording systems need to be upgraded before hybrid streamer combinations can be deployed.

Mike Branston (Schlumberger: Reviewing Fiber Optic Seismic Data Acquisition in Marine Environments: Opportunities and Design Considerations) then provided insights into both the applications of, and pre-survey modeling for DAS acquisition with fiber optics. Although the 'integration of surface and borehole acquisition' was mentioned a couple of times, the content primarily addressed DAS deployed within boreholes (either as walkaways VSPs or for fixed borehole monitoring). Most interesting was the development of two numerical modelling schemes ('infinitesimal strain' and 'finite difference strain') for modelling DAS strain gauge responses, and it is clear that DAS is really coming of age as a flexible, powerful and potentially low cost borehole seismic solution.

Nicolas Tellier (Sercel: 3C MEMS sensors for True Vertical and Orthogonal OBN Sensing) argued that the next generation of OBN units will benefit from multisensor MEMS sensors rather than the geophones used today. MEMS sensors are insensitive to EM noise, and offer low distortion, with (in principle) true amplitude and phase sensing. Various technical features were catalogued, and it was noted that the first commercial deployment of a 'several thousand node' survey using MEMS sensors is about to begin somewhere in the Middle East.

The session then concluded with two efforts to reduce the cost of towed streamer surveys with pragmatic compromises in survey design.

Edysuzaily Kamarudin (Petronas: Embraced Technologies for Pre-Salt Imaging: An Integrated Approach to Address Different Challenges) presented a West Africa case study wherein a 'Compact WAZ' design with three vessels operating simultaneously. A comprehensive survey modeling exercise used finite difference modeling and imaging to compare the merits of various multi-vessel WAZ scenarios for imaging targets below a complex salt regime in a range of water depths (100-2000m). The chosen survey design used a vessel towing a conventional streamer spread and dual-source shooting, and two dual-source vessels operating simultaneously. With reference to the WATS survey design developed by BP in the early-2000s (REF), the Petronas configuration is equivalent to acquiring two 'tiles' of data at the same time. All three port sources were fired with a dithered scheme, and then all three starboard sources were fired with a dithered scheme, and so on. Alternating sail-line directions were also used (all vessels on the 'same geographical side') to enable for positive and negative offsets in the overall survey offset-

azimuth geometry. It was acknowledged that the aggressive simultaneous shooting strategy created some challenges to deblending in processing, and efforts are ongoing to resolve residual blended noise issues.

Magali Collin (TotalEnergies: Wide Streamer Configuration for Exploration Surveys in Deep Offshore – Learnings and Way Forward) then shared their global experience with seven 'ultra-wide' towed streamer configuration over the past three years. Using 1800m as the (current) maximum practical streamer spread width, three surveys with 10 streamers at 150m separation, only survey with 12 streamers at 150m separation, and three surveys with 10 streamers at 200m separation have been acquired. Acknowledging that such configurations suffer from missing near offset coverage, and associated challenges to AVO pursuits and multiple removal, such designs can nevertheless provide low cost exploration insights. Testing with interleaved sail-lines to effectively half the crossline receiver wavefield sampling has been tested, although the benefits in deep water were not significant. Wide-tow multi-source acquisition to improve near offset sampling was not discussed.

### High Frequency Click Trains and Autonomous Node Concepts

The fourth session titled 'MARINE DATA ACQUISITION TECHNOLOGY II' included an adaptation of PAM (passive acoustic monitoring) for Harbour Porpoises, and three novel concepts for reducing the cost of OBN acquisition with autonomous node designs.

Christophe L'Her (Sercel: Efficient and Automatic Detection of Harbour Porpoise Click Trains in Seismic Environments) integrated a new 10 Hz to 180 kHz broadband hydrophone and a detection mechanism based upon click trains rather than unique events into an established towed PAM platform. Although the detection range is relatively limited, only a few modules should be sufficient to detect the unique click train emissions of Harbour Porpoises that often occur above 100 kHz, and are beyond the detection capability of traditional PAM systems.

Three quite different approaches to node-based acquisition were then presented: Self-propelled surface buoys with a suspended dual-sensor unit, self-propelled AUVs that can independently navigate to pre-assigned seafloor locations and then return to the surface for capture, and anchored nodes that free-fall from the surface to the seafloor and detach from the anchor upon command to float back to the surface for retrieval. All three concepts require significant additional capital to reach commercialization with a high inventory, but this was an interesting reminder that 'efficient' technology solutions nevertheless require significant R&D investment—particularly when they pursue fundamentally different methodology.



Nikolay Amelin (Geology Without Limits: Extending Offsets of the 3D Towed Streamer Acquisition) introduced Floatseis; an 11 kg bouy with an internal winch to deploy a hydrophone (or hydrophone + geophone) at a depth 1-20m below the surface. Power is supplied by lithium batteries or hydrogen fuel cells (which can be refueled from a small support vessel in one minute), and an array of such nodes can independently propel themselves to pre-assigned grid locations, including collision-avoidance capabilities, and to potentially within 10m of platforms. The units have been tested to 2.4m wave height (include dampening to reduce noise), and can manage 'station-keeping' locations up to 2 knots current—although power consumption increases noticeably at higher currents.

Figure 4. FloatSeis buoys. Courtesy of [GWL](#).



Constantine Tsingas (Saudi Aramco: Autonomous Underwater Vehicles for Ocean Bottom Surveys: Are We Ready?) showcased six years of development and testing with several iterations of self-propelled AUV design. Two large-scale tests were pursued with 120 AUVs in 2017, and 200 AUVs in 2020, respectively.

Figure 5. One of several prototype AUVs tested by Saudi Aramco.

The stated ambition of the project is to increase OBN survey productivity by 50%, and reduce cost by 30%. Development is now at stage II of III, with large-scale proof-of-concept

testing being the priority. AUVs are deployed from a chute on a vessel (2 minutes per AUV), 84% were able to navigate within 8m of their seafloor target location, and navigate to surface rendezvous locations where they are collected with a basket mechanism (25 at a time). Endurance is 40 days, and range is about 1km with existing navigation protocols.

Satoshi Shimizu (Nippon Marine Enterprises: Free Ocean Bottom Node - Valued for the Sparse Node Technology) then presented their free-fall concept that is simply deployed via a chute on a vessel and sinks to the seafloor (see also REF). Lateral drift from the surface position can be as great as 100-200m in deep water, although plans exist to predict currents and therefore improve the subsurface placement accuracy.

### It's Seismic but Not As You Know It

Day three began with the fifth session titled 'ADVANCES IN SURVEY DESIGN', and included three fundamentally-different approaches to spatial and/or spectral wavefield sampling.

Tilman Kluver (PGS: The Continuous Wavefields Method – Improved Source Side Sampling and Operational Efficiency With Reduced Sound Levels) showcased the 'eSeismic' methodology that fundamentally depends upon the use of continuous source wavefields—most likely derived by triggering individual air guns several times a second with small random time intervals (refer to Figure 6). As such, there is no notion of 'individual shots' assigned to reference grid locations, or any traditional effort to time-align certain shot gathers during deblending processing in an effort to preferentially exploit the incoherency of other shot gathers. Instead, common receiver gathers are reconstructed on a user-specified dense grid. Received sound levels are greatly reduced by comparison to arrays of air guns, and flexibility exists in terms of dense source wavefield sampling with a variety of source deployment strategies to improve survey efficiency.

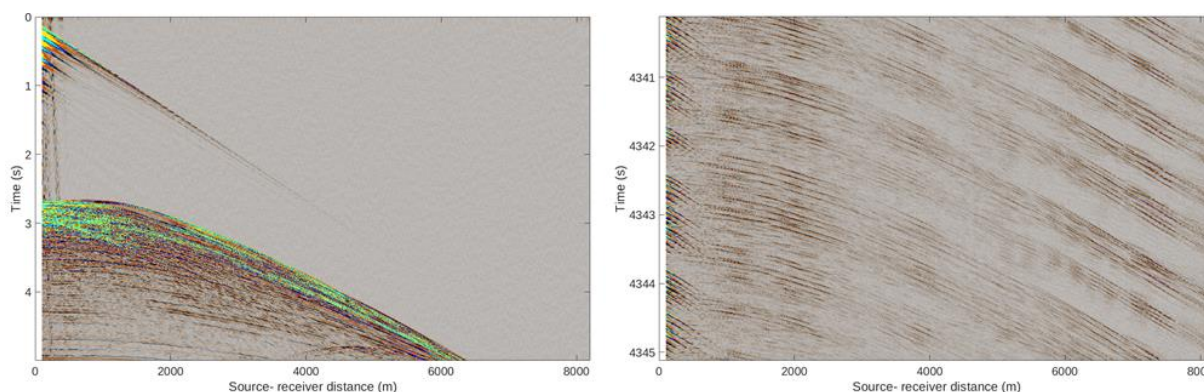


Figure 6. (left) Traditional shot gather for an air gun array fired on a reference grid; (right) Continuous wavefield gather window acquired from continuously triggered individual air guns.

Gerrit Balquiere (Delft University of Technology: Low Frequencies and the Consequence for Seismic Source Design) revisited the DSA (distributed / dispersed / decentralized source array) concept published several times previously by Delft authors. He began by reminding participants how richer low and high frequency content can theoretically benefit seismic image resolution; and illustrated that if achievable, spectral bandwidth-limited sources with dispersed spatial locations, could enable the simultaneous acquisition of a spatially- and spectrally-white wavefield beneficial to seismic imaging. There are clear links to the practical methodology of Tilman Kluver. Gerrit also alluded to [machine learning-based initiatives to enhance the low-frequency content of seismic data](#) as a way to augment the success of DSA-type seismic imaging.

Shotaro Nakayama (INPEX: [Automated Survey Design for Direct Inversion of Compressed Data via the Integration of a Metaheuristic and Machine Learning](#)) also addressed a complementary Delft concept of JMI (joint migration and inversion). A simple synthetic example was used to demonstrate that JMI can estimate reflectivity and velocity directly from 'compressed' data without necessitating deblending or data reconstruction, and can incorporate both primary and multiple reflections. The notion of 'compressed' data is a complex one beyond the scope of this discussion, but the ambition is that strategically-randomized sampling during acquisition can be pursued in a lower-cost manner, and that nevertheless facilitates an accurate recovery of the target signals. Consideration was also given to machine learning-based optimization of DSA survey parameters such as the DSA source locations and source activation times for a given number of receivers, sources, and 'blending fold' (the number of complementary source spectra). Note that [Yang et al. \(2021\)](#) will introduce a solution to simultaneously invert both reflectivity and velocity from traditional marine seismic data.



Session five was concluded by Rajiv Kumar (Schlumberger: Impact of Shot-Time Dithering on Simultaneous Source Acquisition - OBN Scenario), who then returned attention to time dithering strategies during blended acquisition, with dual-source and triple-source OBN examples. Using a variety of shot dithering examples for the same individual gather, as might be expected, larger dither equates to larger randomness and less signal leakage during deblending. There is no fundamental difference in outcome when using linear vs. Gaussian dithering schemes; it was noted that distributed vessels offer better randomness than multi-sources deployed from a single (source) vessel; and regards the environmental footprint of seismic surveys, the received sound levels are not improved by larger dithering (for shooting nevertheless referenced to a traditional shot grid—in contrast to the methodology addressed by Tilman Kluver).

## Multi-Source Air Gun Arrays and Renewed Marine Vibrator Interest

The sixth and final session of the workshop program was titled 'MARINE DATA ACQUISITION TECHNOLOGY III', and combined an OBN case study, two multi-source towed streamer case studies, and two quite different marine vibrator insights.

Jon Wall (Shell) and Chris Walker (BGP) presented 'Brunei's first full Ocean Bottom Node Survey – Planning and Execution'. Acquired for Shell Brunei during 2019-2020 in shallow 5-60m water depth, the complex challenges to the planning and execution of a 7 x 14km OBN were overcome by diligent communication, flexibility and effort. 9,000 nodes on a rolling 175 x 150m template yielded 75m receiver line interval, and used a 25 x 25m source grid. Hybrid streamer-node surveys can be expected more often in logistically challenging settings such as this—compounded by various production infrastructure—and the shared lessons and insights were greatly appreciated.

Carine Roalkvam (PGS: Cost-effective Multisensor Streamer MAZ Acquisition with Wide-Tow Sources and Variable Streamer Length) showcased methods to greatly enhance near-offset coverage and shallow resolution during efficient towed streamer acquisition, including an innovative wide-tow deployment of five sources in the Barents sea. An outer source separation of 315m as used; thereby enabling uniform source line distribution as a complement to dense receiver wavefield sampling. It was noted that the most recent wide-tow multi-source configuration achieved since the survey addressed is six sources distributed over 437.5m. Three long streamer 'tails' enabled deeper refraction FWI model updates, and multi-azimuth (MAZ) shooting was determined to be far more cost effective and practical than multi-vessel WAZ shooting to overcome imaging challenges associated with localized velocity anomalies.

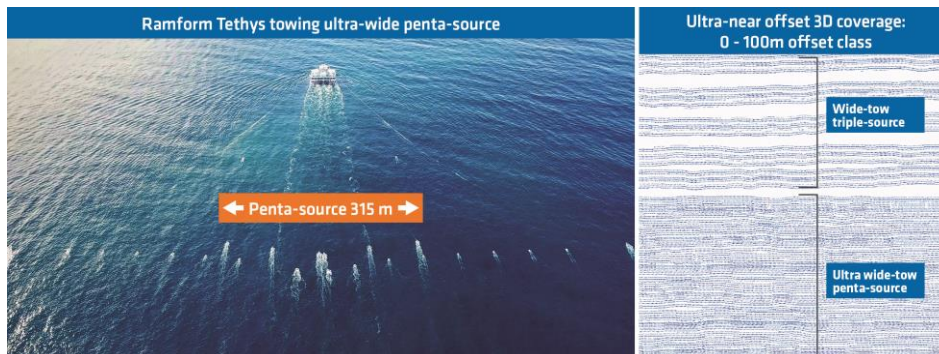


Figure 7. (left) Overhead photo of ultra wide-tow penta-source configuration; (right) Comparison of 0-100 m near offset coverage for wide-tow triple-source vs. ultra wide-tow penta-source towing.

Tasvir Kaur (Petronas: Marine Vibrators: Possibilities of New Alternative Seismic Source in Transition Zone Area: A Case Study from East Malaysia) shared testing Malaysia of an electric flexensional marine vibrator (MV) concept



with a magnetostrictive terfenol-D driver. Two 'triton' units with 8-96 Hz sweep capability, and one 'subtone' unit with 1.5-16 Hz sweep capability are deployed below a shallow-draft catamaran. 2D seismic comparisons to a small air gun array demonstrated equivalent imaging quality and resolution, and demonstrate one again that marine vibrators may offer a lower environmental footprint to traditional air gun sources. Reference is also made to similarly published results using this MV concept in [Pramik et al. \(2015\)](#).

Figure 8. [SAExploration](#) marine vibrator array. Refer also to [Pramik et al. \(2015\)](#).

Hiroaki Ozasa (IHI Corporation: Seismic Surveying With a Deep-Towed Marine Vibrator) presented a very different deep-tow MV concept. A 22 kW, 100 kg electric 'downsized' MV unit with a flexible piston-driven membrane can provide 3-300 Hz sweeps, and be towed at 10-250m depth (includes pressure compensation). The two operating depths discussed were 50m and 225m, with peak output of 180-190 dB presented as being 'equivalent' to a compact air gun array with 213 dB peak output. For reference, a 480 cubic inch air gun array towed at 6m depth has about 232 dB peak sound pressure level (SPL). Examples were shown with a 4 second sweep length, and the main challenge to seismic image quality was the very long period free-surface ghost. A longer sweep would have ghost effects compounded by more complex Doppler motion effects.

Engku Aminulhakim (Petronas: Penta Source 3D Marine Acquisition in the Sarawak Basin Malaysia) gave the final workshop presentation; a case study with a penta-source deployment ahead of the two innermost streamers (12 x 75 m separation). Six uniformly-spaced sub-arrays of air guns were fired in five pairs to act as five unique sources; but with sub-array separation reduced from the nominal 15 m to 12.5 m separation to improve source directivity and enable 12.5 m subline separation. The resultant non-uniform fold distribution presented some challenges to artifact suppression in processing, but the dense receiver wavefield sampling clearly translated to improved near-surface spatial resolution benefits.

## Summary

Overall, the diverse content of this highly professional workshop program conveyed the clear message that many new advances in towed streamer innovations can still be expected, and that the platforms for more efficient seafloor node acquisition are still only starting to emerge. A renewed appetite for complementary acquisition platforms such as marine vibrators and borehole acquisition (most likely enabled with DAS fiber optics) was also evident. The more jarring and recurrent theme throughout all insights into 'new' acquisition concepts was the significant capital efforts required over long timeframes to bring them to fruition—more so when the concepts represent a fundamental departure from traditional hardware platforms. Correspondingly, creative methods that repurpose traditional acquisition hardware and survey design templates can also offer significant data improvements without necessitating expensive engineering development. Finally, the journey towards 'new energy' pursuits, which commonly have a greater focus upon the high-resolution characterization of the near-surface, will benefit from a continuum of complementary acquisition methods that extend the maximum imaging frequency into the kilohertz range. As always, the key technology enabler will be higher efficiency and lower cost solutions.

## Acknowledgments

This summary and the content herein was written independently and without contributions from the SEG workshop participants. All views are of the author alone.

## Further Reading Material

- Recent Advances With Wide-Tow Multi-Sources in Marine Seismic Streamer Acquisition and Imaging (First Break 2020):  
[https://www.pgs.com/globalassets/technical-library/tech-lib-pdfs/fb\\_widmaier\\_et\\_al\\_dec2020\\_wide-tow-sources.pdf](https://www.pgs.com/globalassets/technical-library/tech-lib-pdfs/fb_widmaier_et_al_dec2020_wide-tow-sources.pdf)
- Shallow Resolution | Achieved in Many Ways (TechByte Webinar):  
<https://www.pgs.com/media-and-events/webinar-library/technology-webinars/webinars/shallow-resolution-achieved-in-many-ways/>
- New Shallow Seismic Insights:  
[https://www.pgs.com/globalassets/technical-library/tech-lib-pdfs/industry\\_insights2021\\_01\\_shallow\\_imaging\\_may2021.pdf](https://www.pgs.com/globalassets/technical-library/tech-lib-pdfs/industry_insights2021_01_shallow_imaging_may2021.pdf)
- Continuous wavefields method – Insights from a shallow water field trial:  
[https://www.pgs.com/globalassets/technical-library/tech-lib-pdfs/pgs\\_kluver\\_et\\_al\\_seg2020\\_shallow-seismic.pdf](https://www.pgs.com/globalassets/technical-library/tech-lib-pdfs/pgs_kluver_et_al_seg2020_shallow-seismic.pdf)