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# What's New in OBN Imaging at EAGE 2020?

The source and wavefield spatial sampling of towed streamer acquisition exceeds that of Ocean Bottom Node (OBN) and Ocean Bottom Cable (OBC) acquisition, and the survey costs are considerably less. Nevertheless, the decoupled source and receiver locations, the flexibility of OBN deployment in certain environments, and the growing industry focus upon very low frequency signals and very long offsets for FWI applications are motivating a growing market for OBN. After reviewing some recent developments in the application of Full Wavefield Migration (FWM) and Least-Squares Migration (LSM) of OBN and OBC data, I share a rather contrary perspective on receiver-side spatial sampling, and note how FWM can exploit the decoupled nature of OBN receivers, and may enable sparser (and lower cost) acquisition than is typical. This consideration of sparse and/or irregular OBN acquisition geometry leads to a brief overview of several presentations that address the acoustic imaging of OBN data at the upcoming virtual EAGE conference in December.


## Historical Marine OBN/OBC Acquisition Snapshot

Ocean Bottom Node (OBN) and Ocean Bottom Cable (OBC) surveys physically decouple stationary receivers on the seafloor from the source vessel(s) that operates independently at the surface of the ocean. The increased mobility of source vessels allows them to acquire a uniform grid of shot locations; typically of the order of 50m x 50m, but may be as dense as 25 x 25m. As the daily production rates in square kilometers for OBN/OBC operations is much lower than towed streamer operations (primarily due to the higher source effort, and then the rate of OBN/OBC deployment and retrieval), the typical OBN deployment is a grid with hundreds of meters (or more) between each node, and similarly, hundreds of meters (or more) between each OBC cable. As OBN acquisition is now greatly surpassing OBC acquisition, for convenience, I hereafter simply refer to OBN acquisition, but the principles are mostly applicable to OBC too. R&D efforts are being pursued by several entities to develop robotized nodes using Autonomous Underwater Vehicles (AUVs) for faster operations, but without thousands of such devices being able to operate simultaneously, the spatial sampling between receivers for each shot during OBN operations will expectably always be much coarser than that provided by towed streamer operations. However, source-receiver reciprocity is typically exploited in processing of OBN data to compensate for the poor receiver wavefield sampling, and common receiver gathers based on all the contributing shots per node location benefit from the comparatively dense shot grid sampling.

From a source-receiver aperture and azimuth perspective, OBN operations can record full-azimuth data over the collection of OBNs deployed (the specific area of receivers depends upon the number of available OBNs and their separation), and the maximum useful offset is dictated by the dimensions of the shot grid with respect to the OBN deployment. Where the inventory of OBN receivers is less than the total survey deployment, the OBNs will be redeployed the necessary number of times. The source-receiver aperture (and therefore the source-receiver azimuths) available for towed streamer operations is traditionally dictated by the width of the streamer spread, the length of the streamers, and will be biased by the shooting direction of each sail line. This azimuthal limitation can be improved however, by the use of multi-azimuth (MAZ) or wide-azimuth (WAZ) shooting.

A decision to pursue OBN acquisition over towed streamer acquisition is sometimes linked to Full Waveform Inversion (FWI) being critical for velocity model building in areas affected by salt and other penetration barriers in the overburden; particularly where transmission FWI based upon diving waves is required. OBN will allow very long offsets to be acquired, although the signal-to-noise ratio (SNR) of such events at very low frequencies will determine what the maximum useful offsets are. Note that such an investment is essentially related to the mitigation of cycle skipping at low frequencies in the FWI workflow, and the longer offsets become less relevant at high frequencies when recovering deep model updates.

OBN receivers coupled to the seafloor can also record shear waves, which opens the door to converted wave and fully elastic data processing. I note that most OBN FWI applications to date have not used accelerometer data, and instead rely upon the hydrophone data.

Overall, the greatest challenge to OBN acquisition is the high cost, however, I will discuss developments in seismic imaging below that paradoxically perhaps, allow the OBN density (and therefore the cost of receiver deployment) to be significantly relaxed in various scenarios. This flexibility arises because of the fact that the sources and receivers are physically decoupled, and as mentioned, the source vessel is typically able to acquire a uniformly dense 3D grid of shot locations. I note that the cost of the source effort typically outweighs that of the receiver effort in modern OBN surveys, which is the motivation to pursue highly blended shooting with two or more source vessels operating simultaneously.

## Full Wavefield Imaging with Multi-Component Sensors

Developed for the multisensor GeoStreamer platform, and now also applicable to multisensor OBN/OBC data, Separated Wavefield Imaging (SWIM) exploits the dense illumination provided by surface multiples, and provides substantially better shallow seismic images than possible using reflections only. Original applications, however, were limited to the first several hundred meters below the seafloor due to ‘crosstalk’ imaging artifacts becoming prevalent at larger depths. Nevertheless, shallow high-frequency SWIM images can be seamlessly merged with conventional (primaries-only) depth images at larger depths in an efficient manner. Full Wavefield Migration (FWM) using both primary reflections and surface multiples extends the power of SWIM to exploit the illumination from the full seismic wavefield. FWM is particularly suited to multi-component OBN imaging thanks to the illumination provided by both positive and negative offsets, and the ability to pursue wavefield separation of the up-going and down-going receiver wavefields. As discussed below, FWM also enables considerable flexibility when designing the deployment of OBN surveys.

The first published SWIM applications to OBC data were specific to the deepwater Jubarte PRM (Permanent Reservoir Monitoring) installation operated by Petrobras in offshore Brazil. The stationary nature of PRM receivers over consecutive vintages make such data an excellent test platform for new imaging technologies. Example benefits of SWIM specific to the Jubarte PRM installation included the ability to extend the imaging aperture over a much larger area than traditional mirror migration; thereby being able to observe pressure changes associated with injector wells outside the receiver array. The same data were also used to demonstrate how robust SWIM imaging is when the OBN effort is decimated. More recently, a series of PRM and OBC case studies imaged using SWIM and LS-FWM in the North Sea include shallow imaging and 4D monitoring over the Snorre Field; shallow imaging for geohazards over the Culzean field; and further decimation testing of the receivers from an OBC survey. As many operators seek to combine overlapping data coverage from towed streamer and OBN/OBC surveys for 4D monitoring, the image-domain implementation of Least-Squares Migration (LSM) has been extended to account from the quite significant differences in acquisition geometry between such datasets. The computation of point spread functions (PSFs) can be extended in a ‘joint reflectivity inversion’ to compute multidimensional ‘cross-survey PSFs (XPSFs: see Figure 1). This approach enabled more robust recovery of 4D effects with less 4D noise than independently applying LSM to the different datasets.

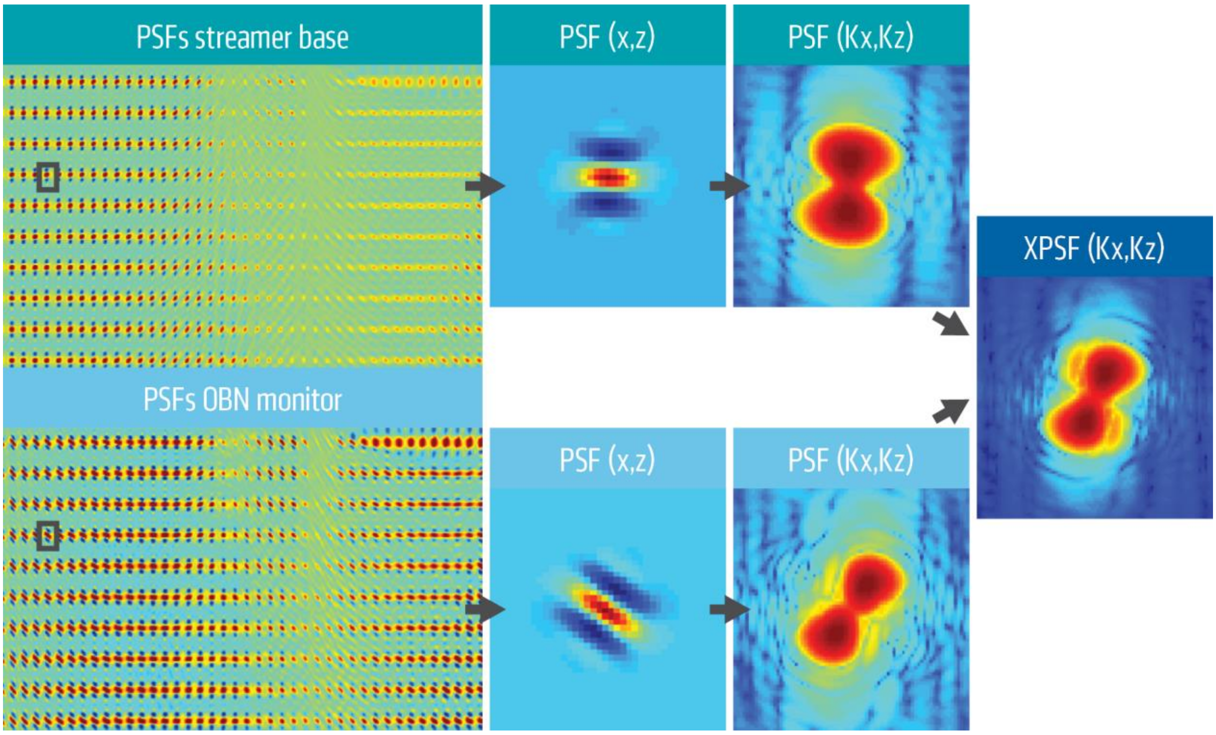


*Figure 1. Example of a point spread function (PSF) grid from a generic model representing towed streamer acquisition (top) and OBN acquisition (bottom). Single PSFs are shown in both the depth domain (x,z) and wave number domain (Kx, Kz). The cross-survey PSF (XPSF), shown in the far right, is used in the 4D joint reflectivity inversion. From Lecerf and Besselievre (2018), First Break.*

## New OBN Developments at EAGE 2020

A few common themes can be identified from the upcoming EAGE (European Association of Geoscientists and Engineers) technical program; consistent also with the SEG (Society of Exploration Geophysicists) technical program recently held in September:

- Can irregular OBN deployments be accommodated?
- How 'sparse' can OBN deployments be?
- What very low frequency (VLF) source concepts are emerging that might complement the value of OBN acquisition for yielding robust FWI model updates?

CGG and CNOOC use a North Sea case study to conclude that 300 x 100m OBN spacing would have been acceptable for 4D monitoring, rather than the 300 x 50m OBN deployment actually used (25 x 25m shot grid), but also observe that high OBN density is required for 4D imaging when a traditional processing flow is used. Aforementioned publications suggest that incorporating multiples into OBN/OBC imaging offer several opportunities, and a 2016 publication by Statoil and PGS addressed the recovery of missing shallow data from (non-repeated) OBC acquisition when using multiples in 4D imaging (i.e. SWIM). Several presentations at EAGE2020 pursue similarly new directions. Shell present their implementation of Least-Squares reverse time migration (LS-RTM) that includes surface multiples. Consistent with published PGS implementations, crosstalk noise is resolved, and the extended subsurface illumination benefits from the fact that primaries and surface multiples are explained by the same reflectivity. The method described is particularly effective for OBN and DAS VSP (Distributed Acoustic Sensing fiber optics in Vertical Seismic Profiling) type acquisitions; where use of the downgoing wavefield avoids explicit knowledge of the source wavelet being necessary. PGS and Total take an even more expansive approach, and investigate the impact of various non-traditional OBN geometries on the seismic image resulting from FWM of both primaries and multiples (refer to Figure 2). A unique 'donut' design is proposed for complementary benefits to both transmission FWI and FWM, and evidence is given that significantly less OBN density might be reasonable for 4D monitoring than traditional dogma. The latter study also points to the potential deployment of non-uniform OBN geometries. Building upon earlier published academic work by the SLIM consortium at UBC, authors from Delft University address the combined challenges of non-uniform and non-repeatable acquisition geometry and blended data using a simultaneous 4D inversion scheme. Non-replicated OBN geometries are designed that improve the 4D signal by 6 dB in comparison to existing geometries.

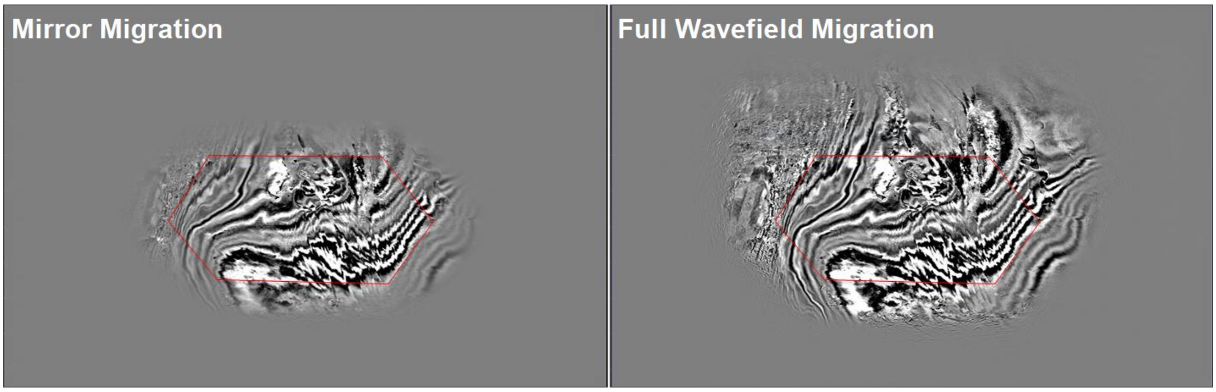


*Figure 2. In both panels the hexagon polygon denotes the lateral extent of an OBN deployment on the seafloor. In comparison to traditional mirror migration (left), Full Wavefield Migration (right) images a much larger spatial area of the subsurface. Based upon Lecerf et al. (2020).*

Regards very low frequency source concepts, LISS and Shell describe testing with a 26,500 cubic inch 'Tuned Pulse Source'; a 'pneumatic' source concept that releases air into the water with pressure two-to-three times lower than air guns. The long firing chambers correspondingly have a long rise time to peak pressure, and produce low-frequency bubble oscillations with a resonance in the order of 3 Hz. The resulting improvement in low frequency output is in the order of 20 dB over the 1-3 Hz range when compared to a 5,110 cubic inch air gun array (refer to Figure 3). Given that ION have also been testing large volume air gun concepts with similar ambitions, the question must (once again) be asked whether more complex marine vibrator concepts touted for very low frequency applications will now ever justify commercialization—despite decades of stop-start development. Another apparent relevant benefit of the pneumatic source concept in comparison to resonating large marine vibrators is that the amplitudes decay more slowly below the 3 Hz peak.

A notable PP/PS 4D application of OBN data by Lundin and WesternGeco over the Edvard Grieg illustrates that the insensitivity of PS (converted wave) data to fluid effects in the reservoir translate to an enhanced ability to isolate pressure effects. For brevity, however, I have ignored other OBN presentations that use converted wave data, and focused here upon acoustic applications of OBN data.

Other OBN presentations at EAGE 2020 describe case studies where 'sparse' OBN deployments are primarily used to augment FWI success in high exploration risk regimes affected by salt; with the ambition of improving subsalt imaging courtesy of more accurate model updates. The high cost of OBN acquisition has led to multi-vessel shooting to increase survey efficiency; at the expense of highly blended data. Another common aspect of OBN presentations therefore describe deblending efforts in signal processing. Given that much of the motivation to use OBN is often a desire to record higher SNR at very low frequencies to overcome cycle skipping effects during the initial iterations of transmission FWI workflows, it is no surprise that many contemporary Deep Learning efforts focus upon low frequency extension. For example, ExxonMobil use the very low frequency content from sparse OBN data to train a neural network, that in turn, extends the low frequency content of towed streamer data; thereby potentially reducing cycle-skipping effects upon FWI.

## Summary

Several EAGE 2020 authors explore ways to either accommodate the challenges of sparse and/or irregular OBN acquisition during imaging, or adapt full wavefield imaging technologies to reduce cost and enable deliberately sparse and/or irregular OBN acquisition. It is beyond the scope of the discussion here, but I note that the FWI-driven focus upon ultra-long offsets is driven by the recovery of phase / travel time information for velocity model building, and neglects amplitude information. The next chapter in OBN imaging will hopefully return to the long-held ambition of recovering earth properties such as density.

## Acknowledgements

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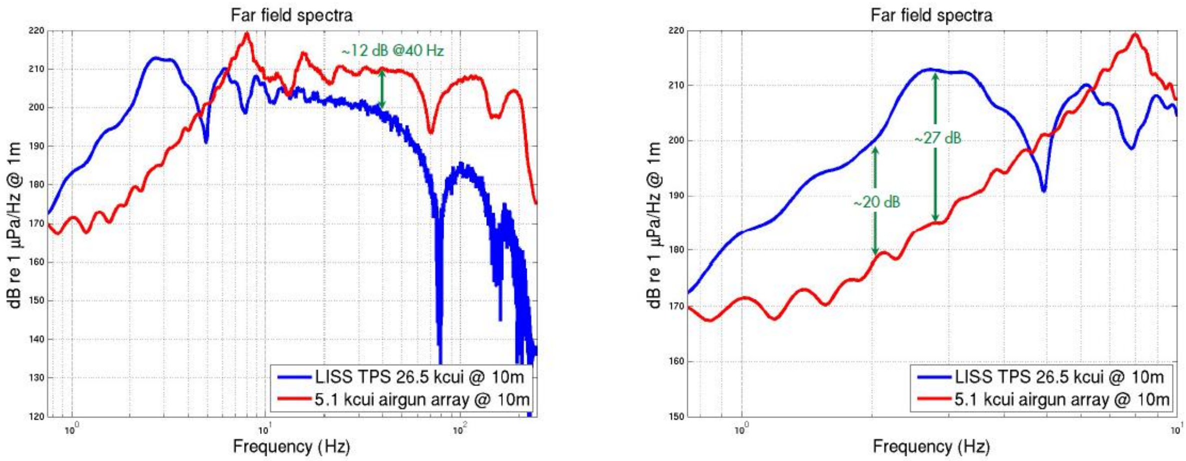


*Figure 3. Frequency domain far field spectra comparison of LISS' 26,500 cu.in TPS (blue) to a 5,110 cu.in conventional air gun array (red) show >20 dB uplift in the 1-3 Hz band by the TPS. Seismic data courtesy of TGS and WesternGeco, Copyright of Shell Global Solutions International B.V.*