Exploration OBN and streamer survey design – maximizing extended-frequency sources and Full Waveform Inversion

Milos Cvetkovic, Martin Widmaier, Marc Rocke, Curt Schneider, Carsten Udengaard, David Brookes, Simon Baldock, Greg Nash, Richard Huang and, Ashish Misra, TGS

Summary

Extended-frequency sources or point sources developed in the last two decades, such as Wolfspar® (Dellinger et al., 2016), the Tuned Pulse Source (TPS) (Ronen and Chelminski, 2017), and Gemini (Brittan et al., 2020), have been primarily designed to provide lower frequency data for Full Waveform Inversion (FWI). These new sources also allow for better imaging of deeper targets in salt and volcanic basins, and have other advantages in processing (Rocke et al., 2024). However, because of high-volume chambers they need longer refill times and have other operational characteristics that restrict survey design compared to most traditional air-gun arrays.

In this abstract we will show how we iterate standard survey design practices when working with operational requirements for the Gemini source in exploration settings. We first show a sparse OBN survey in Gulf of Mexico or Gulf of America (GoM / GoA) where we try to maximize shot sampling in the field with quad-tow sources, while still acquiring long offset and full azimuth data without increasing survey duration and cost. We start with modeling on real and synthetic data to propose node and source spacing, and offsets needed to improve existing models with FWI up to source rock and basement level. We then get quad-tow extended source in-field refill times with available vessels and other operational parameters, that we use to adjust our shooting and dithering scheme. We run another pass of modeling, low frequency FWI and imaging on synthetic data to validate final acquisition parameters. The proposed survey is the first sparse OBN survey with an extended-frequency source in quad-tow configuration with relatively dense shot grid of 75 m x 75 m.

For streamer projects with Gemini sources, we have seen several configurations deployed in various salt basins offshore West Africa and Mediterranean (Donaldson et al., 2024, Ibanez et al., 2025). We will present details and results for ½ WAZ acquisition offshore Angola where we deploy 2 triple-source Gemini. We balance the long offsets (10 km) and azimuthal coverage (½WAZ), while maximizing shot spacing that is operationally permitted.

Introduction

Requirements for surveys that would optimize performance of FWI are not dissimilar to any other 3D seismic – all frequency, all offsets, all azimuths and dense sampling in all directions. Similar to other survey designs, there are physical and practical boundaries that lead us to subsets of these requirements that are fit for purpose for particular survey and targets.
These acquisition parameters need to be further revised if we use extended-frequency sources such as Wolfspar®, TPS or Gemini, as these high-capacity sources are more difficult to refill within a short period of time. However, the benefits of using these sources both on the low (FWI) and high end of the spectrum (environmentally more friendly), justify additional investment and adjustments to existing workflow and best practices.

Methodology

For exploration survey design, we start with exploration targets we are trying to model build and image based on the best available data, which is usually limited in terms of coverage and quality. Even for sparse OBN projects in GoM / GoA and other well established hydrocarbon provinces, we need to acknowledge that input data for survey design will still have large model uncertainties, especially below salt and for older, deeper sediments closer to economic basements.

From here, we can establish initial sets of parameters such as minimum required offsets needed for FWI, azimuthal coverages, “clean” record length, shot and receiver density. We do this with combination of workflows, from simple 2D and 3D raytracing, FWI kernels (Tshering et al., 2024) or full 2D and 3D FD modeling and migration workflows (Cvetkovic et al., 2014). We then consider environmental and regulatory requirements, that can sometimes be restrictive no matter what the proposed technology offerings are. For example, for Brasil offshore marine acquisition, there is minimum source vessel distance of 60 km that eliminates a lot of OBN and WAZ streamer geometries.

For extended frequency sources with large volume chambers, like Gemini (8,000 in³) and TPS (28,000 in³) compressor capacity and air delivery systems affect refill times and need to be considered when designing a survey. Also, different vessels will have slightly different capabilities, even within the same fleet or vessel provider, all interplaying into sampling requirements. Another set of requirements comes from blending or self-blending noise, along with natural or induced dithering scheme.

We find that the iterative loop of survey design input data parameters and exchange between different teams leads to fit for purpose solutions that will achieve model building and imaging objectives but will also deliver on environmental, regulatory and operational goals.

Sparse OBN Case Study

The first case study comes from Mississippi Canyon and Ewing Banks area of GoM / GoA and represents the fourth phase of Amendment sparse OBN surveys. We are building on experience from previous phases and current industry trends and aim to design a survey with extended frequency sources, long offsets and dense shot coverage.

Node spacing and required offsets are coming from real and synthetic data decimation studies specifically built for eastern parts of GoM / GoA. For node spacing we use 1,000 m by 1,200 m grid with possible infill nodes on a denser grid based on node availability. For required offsets, we see that 20 km of shot halo will allow for 25 km of minimum – maximum offsets within the node patch. We also test alternative source geometries with combination of real and synthetic data (Huang et al., 2025) and decide on final 10 km and 20 km halo interleaving source lines (Figure 1 (a)).

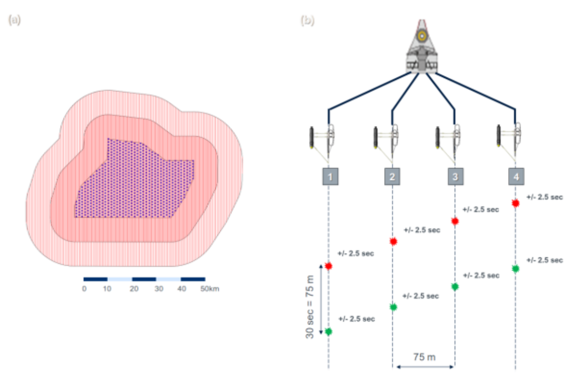

Figure 1: Amendment Phase 4 geometry - (a) node (blue) and shot (red) position map, with node outline and 10km and 20km respective shot halo. (b) Shooting configuration with quad-tow Gemini.

For the shot grid, we start with 50 m by 100 m, that has been used on most sparse OBN surveys in the GoM/GoA.

Since Gemini is the only source to be used for this survey, we see no issue maintaining the above-mentioned grid in two vessels triple source configuration. However, we can improve source efficiency by 33% if we are able to tow four sources (quad-tow) and maintain the same cross line spacing. In order to achieve this, we first test quad-towing capabilities for two different vessels that would be available for this survey. Based on refill tests done at the same time, we can either achieve 50 m shot spacing with reduced pressure (1,850psi) or 70 m shot spacing with typically used 2,000psi. After further normalization of required air-delivery system and compressor capacity between the vessels, we propose 75 m by 75 m source grid with 2,000 psi with nominal vessel speed of 4.7 knots. We use synthetic model with checkboard to show that the difference between DM FWI updates from currently used 50 m x100 m and proposed 75 m x 75 m is negligible for this type of survey (Figure 2).

For shooting scheme, we use a flip-flop-flap-flup configuration with large dither window of +/- 2.5s to preserve low frequencies. For dithering we modified a workflow based on Maiza and Hodges 2024 and added further QCs to an already robust set (Figure 3), to allow for optimal FISTA de-blending results. Receiver gathers from first set of QC nodes before and after de-blending are shown in Figure 4.

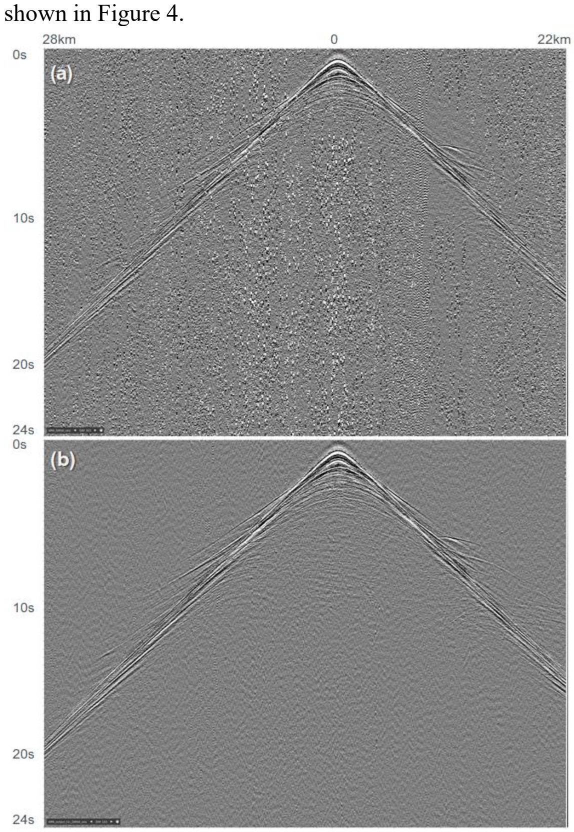

Figure 4: Amendment Phase 4 OBN nodes data without (a) and with (b) preliminary de-blending.

Streamer ½ WAZ Case Study

Gemini as a primary source for exploration streamer surveys have been used in the last few years in the Mediterranean and Red Sea (Donaldson et al., 2024, Ibanez et al., 2025). A number of different configurations have been tested in the field, balancing offset and azimuth coverage and shot density, which is harder to balance for towed streamer surveys.

For deep-water offshore Angola survey, TGS has acquired a ½ WAZ or one-sided WAZ setup, with the main vessel towing 12 streamers of 10,000 m length, 150 m apart, and triple-source. The second source vessel is also

triple-source Gemini in ½ wide azimuth position, 1.8 km to the side and halfway down the spread length, in order to increase azimuthal coverage. (Figure 5).
Following findings from Donaldson et al., we balance refill times for two different vessels, by setting nominal pressure of 1,900 psi and achieving 100 m pop spacing (for individual gun) or 16.667 m shot spacing. Based on calibrated source modeling we observe minimal effect on low frequencies of the spectra compared to most commonly often used 2,000 psi. For randomization, we use the same dithering scheme (Bekara and Hodges, 2024) without further modifications. For designature purposes and wavelet estimation, we improve recording of near field hydrophones by adjusting position and stability along the spreader bar similar to previous acquired streamer surveys in Mediterranean Sea.

Figure 6 shows Ultra-Fast Track Post Stack Depth Migration with initial velocity model and preliminary pre-processing. Input data for migration has initial de-blending, de-noise and limited de-multiple and is sampled to 8ms. To highlight benefits of low frequency source we show 2-3Hz low cut filter stack (a), simulating standard air-gun array source and comparing it to full bandwidth, non-filtered stack (b). Arrows point to benefits of low frequencies in steep and overturned salt flanks that will allow for initial salt model interpretation. Although FWI is data driven velocity update, because of streamer limited offset and azimuth coverage, good starting model with initial salt interpretation is still needed. In this part of offshore Angola basin, there is limited coverage of 3D seismic data, so legacy salt models cannot be used for starting model for FWI as-is. Ibanez et al., 2025, show that even with good low frequency data and long offsets (up to 24 km) and elastic FWI, starting model needs multiple constraints in complex geological settings, such as refined interpretation of salt and pre-salt trends estimated from potential fields methods.

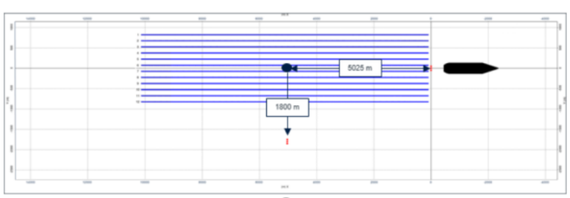

Figure 5: Angola MC ½ WAZ streamer survey geometry.

Conclusions

Designing a survey to maximize the use of FWI and extended-frequency sources in exploration settings presents an iterative process. We show an OBN and a streamer project in salt basins settings where we achieved model building and imaging subsurface sampling requirements tailored to area of interest while making it operationally feasible.

Due to environmental and other benefits, we see increased use of extended-frequency new sources not just in exploration but in production settings, 3D and 4D OBN as well as NAZ streamer surveys. Further improvements in source efficiency can be expected, from in-field operations, hardware and tailored survey design for 4D OBN and 4D FWI.

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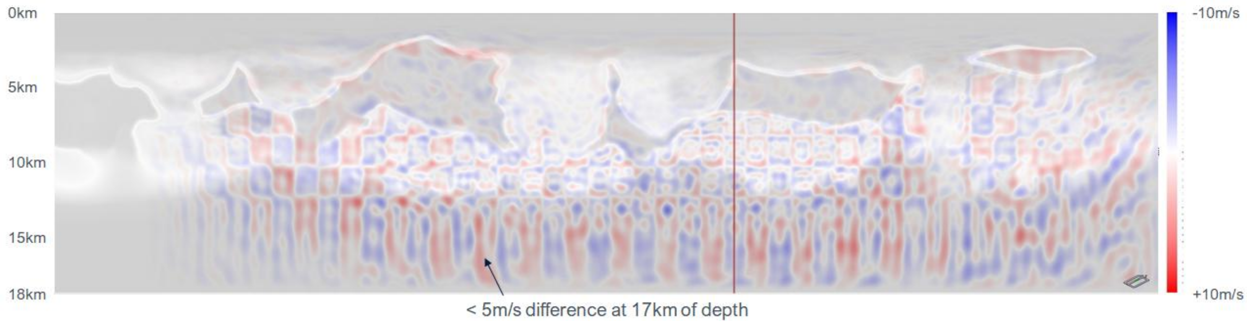

Figure 2: Difference between DM FWI updates from 50m x100m and 75mx75m shot grid with synthetic model with checkboard. Background velocities are from neighboring real sparse OBN dataset.

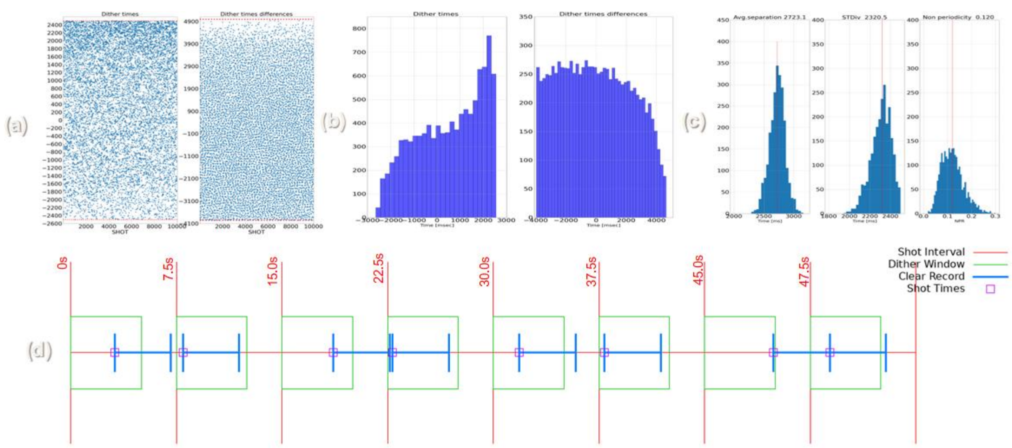

Figure 3: Robust set of QCs for dithering scheme for proposed shooting configuration: (a) Dithering time and difference scatter plot (a) and histogram (b), separation QC histogram (c) and graphical representation of dithering series for one of the vessels (d).

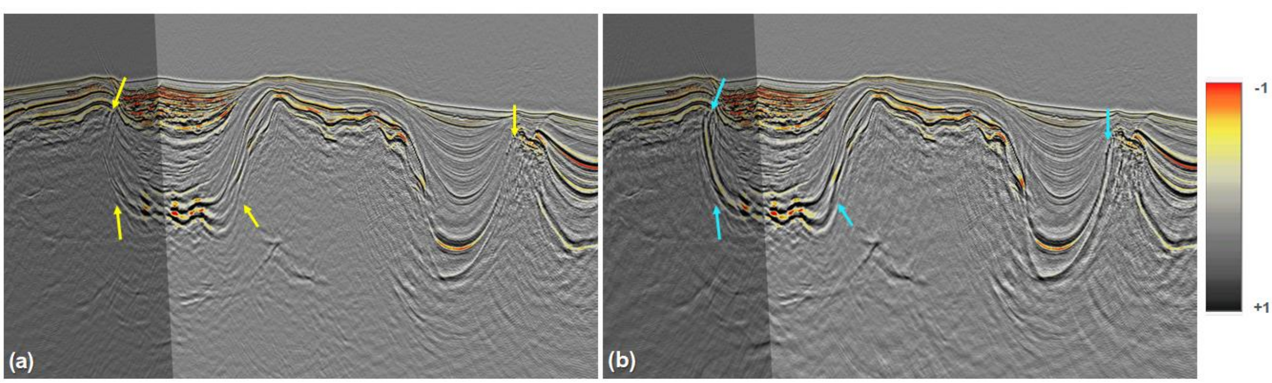

Figure 6: Ultra-Fast Track Post Stack Depth Migration with initial velocity model, 2-3Hz low cut filter stack (a), simulating standard air-gun array source and full bandwidth Gemini source (b). Arrows point to benefits of low frequencies for imaging steep and overturned salt flanks.