A comparison of extended frequency and conventional sources from offshore Angola

Introduction

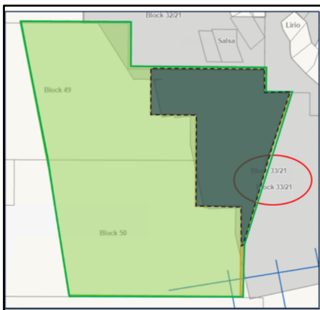
The last five years have been notable for the increased utilization of low frequency sources. Wolfspar® (Dellinger et al., 2016) and the Tuned Pulse Source (TPS) (Ronen and Chelminski, 2017) have been designed to provide low frequency data for Full Waveform Inversion (FWI). Others, such as the Gemini extended frequency source (Brittan et al., 2020), are designed to generate low frequencies and higher frequencies. The extended frequency source has been successfully paired with multisensor streamers in the Eastern Mediterranean (Donaldson *et al.*, 2024). Multisensor streamers provide high S/N ratio, broadband data that complement well the enhanced low frequencies of the extended frequency source. Here we review the performance of this source on a recent one-sided wide-azimuth project acquired offshore Angola and compare the output with overlapping, recently reprocessed legacy data acquired with a conventional source.

Method

The extended frequency source (Udengaard *et al.,* 2023) is a novel marine source solution that utilizes a single-element (8000 cu. in.) designed to generate low frequencies down to at least 1 Hz as well as high frequencies, making it suitable as the sole source for a range of exploration objectives. It also generates ~32 dB less energy at 800 Hz compared to conventional sources, which is advantageous from an environmental modelling perspective (Goertz *et al.*, 2024). Within the seismic bandwidth the extended frequency source operates as a point source bringing numerous advantages to data processing. Several processing steps such as bubble removal, source deghosting, and zero phasing are simplified because there is less angular or azimuthal variation to the source signature – meaning that the source wavelet is consistent regardless of position, and only a 1D operator is needed. Moreover, a single wavelet can be used as a target wavelet for the FWI workflow. Integral to the success of these steps is a stable wavelet and an accurate estimate of the wavelet using near field hydrophone (NFH) data.

Results

In 2024-2025 TGS acquired a multi-client exploration survey offshore Angola using a one-sided WAZ configuration (Figure 1). Twelve 10 km streamers were towed 150 m apart. A total of six extended frequency sources were deployed, three on the streamer vessel and three on an additional source vessel that was positioned midway down the streamers with a lateral offset of 1800 m. The shot point interval (the distance between the same source firing) was 100 m, corresponding to a pop interval of 16.667 m, giving a fold of 50. The average bottom-speed of the vessel was 4.4 kts, allowing for a refill time sufficient to refill the 8000 cu. in. sources. The target pressure was 1900 psi, in the field the mean pressure across all 6 sources was slightly above the target pressure.



Survey	Block 33	Block 49/50
Acquisition Year	2000	2025
Survey Size	4,380 km²	8681 km²
Source volume	3210 in³	8000 in³
Source depth	5 m	8 m
Shot point interval	25 m flip-flop	33.33 m flip-flop-flap
Number of streamers	10	12
Streamer length	4,500 m	10,050 m
Number of channels	3,600	9660
Fold	45	50
Streamer separation	100 m	150
Group interval	12.5 m	12.5
Streamer depth	6 m	20 m
Acquisition sample rate	2 ms	2 ms
Record length	8 sec	

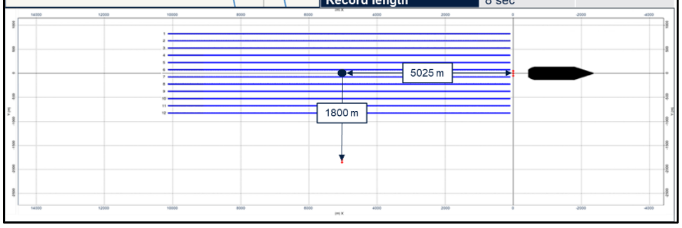


Figure 1 *top: Key acquisition parameters for the new acquisition (Block 49/50) and the legacy (Block 33); bottom: vessel layout for the new acquisition.*

Figure 2A, shows the wavelet stability achieved during the survey. The main challenge encountered during acquisition related to the placement of the near field hydrophones (NFH) with respect to the large bubble produced by the source in order to ensure stability. The three leftmost sections show the average shot-by-shot controlled signatures (SBS-CS) for the streamer vessel and the three rightmost sections show the average SBS-CS for the source vessel. Figure 2B shows the average SBS-CS for both vessels compared to the wavelet extracted from the seismic. The good match between the SBS-CS wavelet and the data derived wavelet validates the use of the SBS-CS wavelet for signal processing and FWI. The amplitude spectra of the wavelets are shown in Figure 2C.

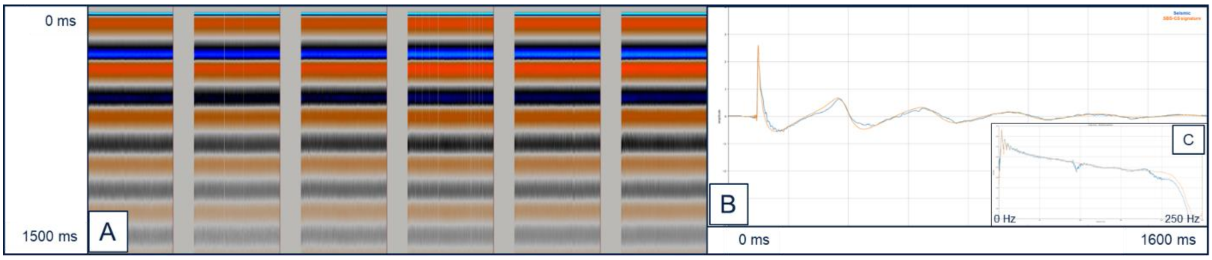


Figure 2 A): SBS-CS wavelets for both vessels; B): TX domain representation of the SBS-CS signature (orange) and a data extracted wavelet; C): amplitude spectra for the two wavelets shown in 2B.

The overlap between the new acquisition and the legacy data provides an opportunity to compare the characteristics of the extended frequency source with those of a conventional source. Figure 3A compares the two wavelets. The lower peak amplitude of the extended frequency source can be seen clearly. Figure 3B shows amplitude spectra plotted with a log scale for the frequency axis. The peak frequency of the extended frequency source is at ~3.4 Hz and the source exhibits approximately 10 dB more energy compared to the conventional source down to ~1 Hz. At frequencies above 30 Hz the extended frequency source shows lower amplitudes than the conventional source.

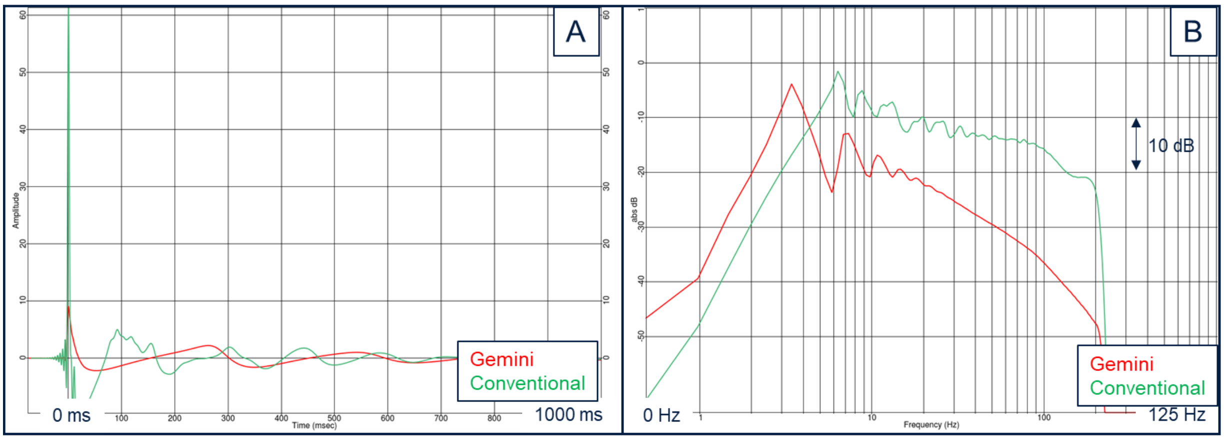


Figure 3 *A): the extended frequency source compared to the conventional source; B): log amplitude spectra for the two wavelets shown in 3B. (Note: the conventional (legacy) source wavelet is estimated based on the acquisition vessel used).*

Figure 4 compares stacked data after regularization for a common inline in the overlap zone. Higher low frequency content is observed for the extended frequency source (figure 4B). The blue and red rectangles in the upper right of Figures 4A and 4B indicate the location of the analysis window for the amplitude spectra in Figure 4C. The extended frequency source is ~14 dB higher than the conventional source at 2 Hz, however, amplitudes are ~5.5 dB less compared to the conventional source at 60 Hz.

To better understand the differences between the two sources the frequency of the -6dB down point (dotted blue line in Figure 4C) was mapped on regularized stack data for the conventional and extended frequency sources. The analysis window was 1 s long, following the water bottom. The results are shown in Figure 5. The conventional source data have less low frequency content, with a mean frequency of ~5 Hz, whereas the extended frequency source has a mean frequency of ~2 Hz.

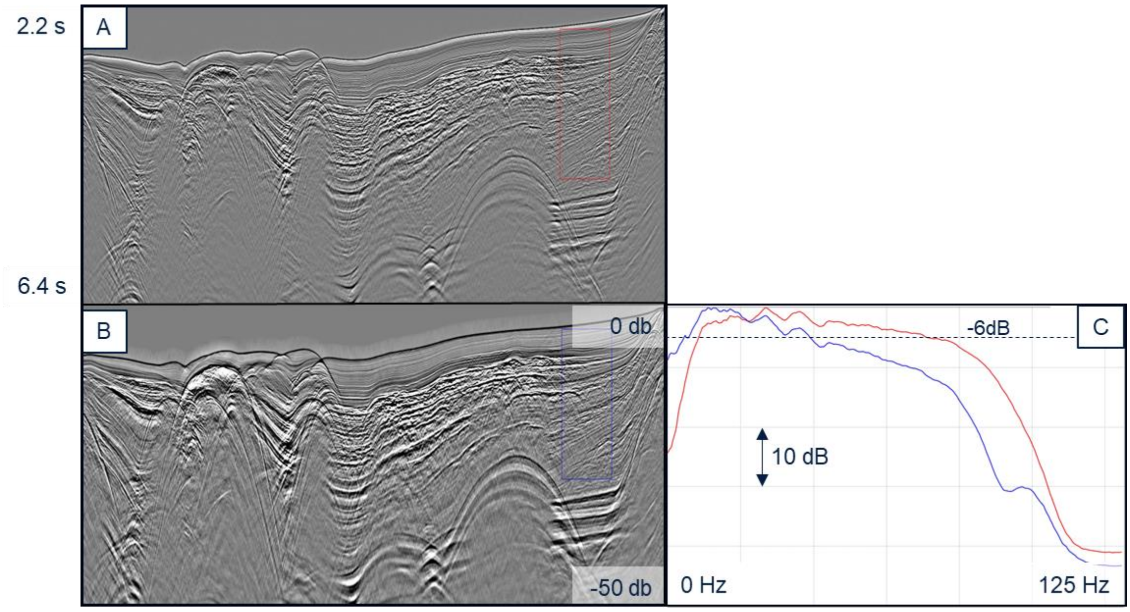


Figure 4: *pre-processed stacks after regularization; A) conventional source; B) extended frequency source; C) Amplitude spectra*

The effect of these low frequency differences can be seen by examining octave panels of the stack data (Figure 6). While the 0-2 Hz panel for the conventional source is effectively empty, the extended frequency source shows strong reflectivity with good S/N ratio. At high frequencies although the conventional source amplitudes are higher in the 32-64 Hz panel, the difference with the conventional source is not large.

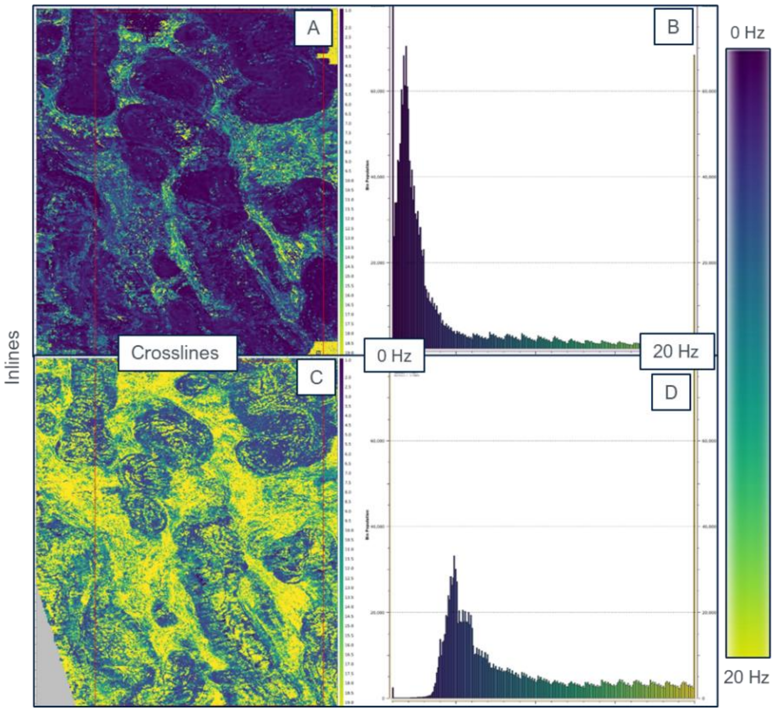


Figure 5: *maps of the frequency at -6dB down. The dimensions of the map are 27 km x 31 km; A and B) map and histogram for the extended frequency source; C and D) map and histogram for the conventional source.*

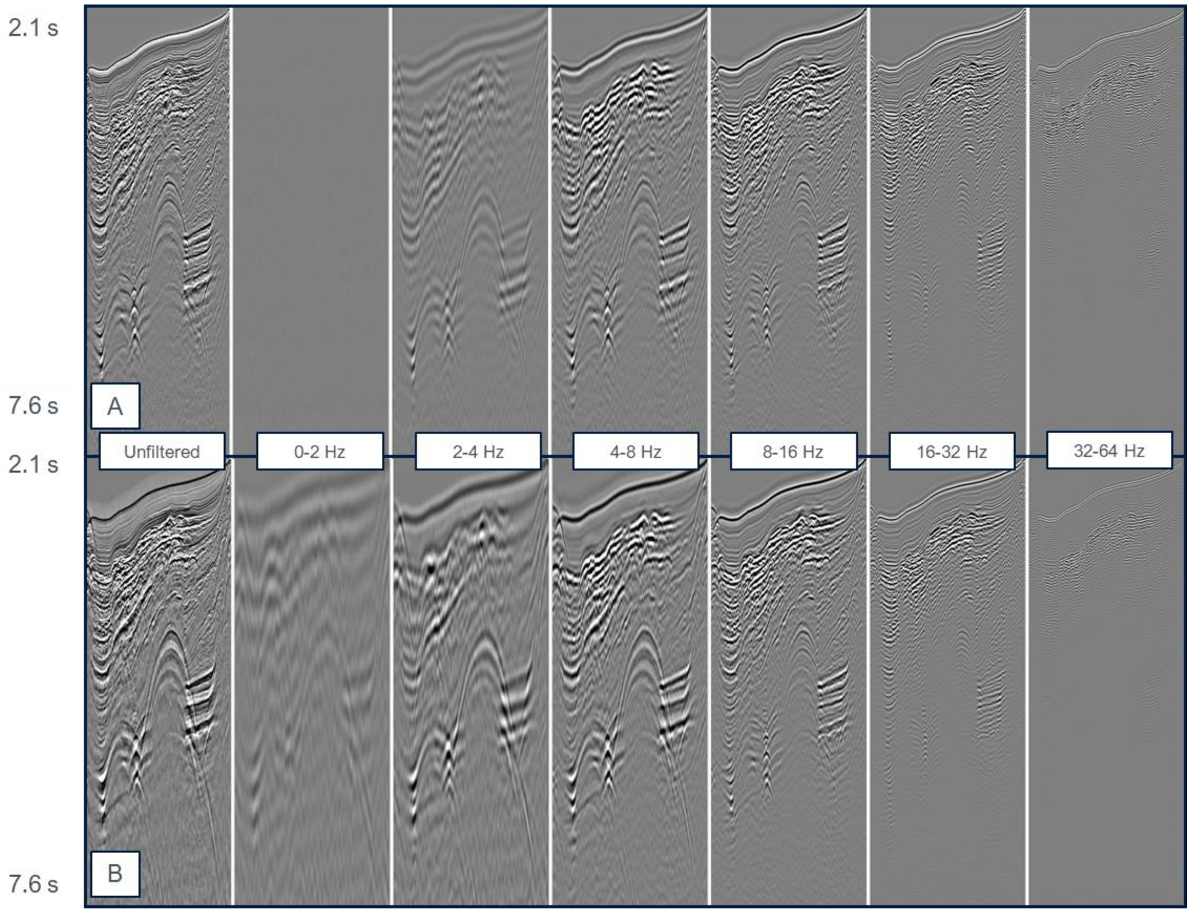


Figure 6*: octave panels; A) conventional source; B) extended frequency source.*

Conclusions

Extended and low frequency sources are now and indispensable part of seismic exploration. We have shown that the Gemini extended frequency source, combined with an innovative multi-vessel streamer design has delivered enhanced low frequencies for processing and velocity model building in a survey acquired offshore Angola.

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