Gemini: a fully operational broadband source for model building and imaging

Carsten Udengaard, David Brookes, and Hector Flores, TGS*

Summary

With more and more marine seismic surveys utilizing Full Waveform Inversion for high quality velocity models it will be beneficial to generate additional low frequency energy beyond standard marine air gun arrays. The Gemini source is a novel solution to generating more low frequency energy for FWI, while maintaining sufficiently high frequency energy for typical processing and imaging workflows. This paper will give a brief history of the source and show the field trial data acquired during the Engagement sparse Ocean Bottom Node survey directly comparable to standard air gun arrays. The OBN data will be shown both in time domain, wavelets, and also in the image domain. The source is also significantly more environmentally friendly than typical air gun arrays. At 800 Hz Gemini is more than 32 dB below other air gun sources, which greatly reduces the risks and harm to marine mammals. A recent survey used the Gemini source as a primary source for the survey, and operational efficiency was better than standard marine air gun arrays.

Introduction

Many new marine seismic surveys are acquired with the intent for both Full Waveform Inversion (FWI) velocity model building and traditional imaging using the recorded reflection seismic data. To improve the results of FWI there is a benefit to generate source signal at low frequencies. Multiple methods have been attempted to generate lower frequency energy, for example with marine vibrators (Dellinger et al, 2016; Tenghamn et al, 2022) or by tuning a standard air gun array with much larger guns (Hopperstad et al, 2012). Many of these methods of generating lower peak energy sacrifice mid and high frequency energy, which limits the potential uses of the survey. The Gemini Enhanced Frequency Source (EFS) is designed to generate more low frequency energy than conventional air gun arrays while maintaining energy in typical imaging frequencies. We will show time and image domain data acquired with the enhanced frequency source compared with a conventional air gun array.

From the Rayleigh-Willis formulation (Willis, 1941) we know increasing the chamber volume of an air gun source will lower the peak frequency of the source. The Gemini EFS source is a single large chamber air gun with ports fore and aft of the chamber separated by approximately two meters, the examples in this paper are with an 8000 cubic inch chamber operated at 2000 psi. The peak frequency of the bubble is expected to be near 3.4 Hz. The source is designed to be directly compatible with existing source vessels, without the need for increased umbilical sizes.

Method

We will compare a standard air gun source array and the enhanced frequency source into a collection of over 500 node locations, spaced on a 1200 m by 1200 m grid, from a field trial performed at the end of the Engagement 1 sparse node survey in the Gulf of Mexico. During the test, offsets exceeding 50 km were acquired with both sources. The data from both sources are compared as azimuthal and angular signatures, by wavelet frequency content, and through Reverse Time Migration (RTM) results. Both sources were recorded with near field hydrophones for determining source signatures. Comparable source lines were acquired using both sources. The analysis of the data is limited to the hydrophone component with minimal additional adaptive signal processing applied to keep comparisons fair, with varied source spacings and the presence of variable background source blending from other nearby surveys.

Examples

Figure 1 shows collocated source points from the two sources into a common node location. No debubble operator has been applied to the data, to show the raw recorded values. The examples in Figure 1(a) and 1(c) show the near offset data out to 5 km offset. In Figures 1(b) and 1(d) the offset range is 43 km to 52 km, this shows even with a single gun long offset data can be recorded and is useable for FWI as direct arrival and diving wave energy can be clearly observed. From the raw data in the short offset window higher frequency reflection data can be clearly seen in the enhanced frequency.

Observations

The enhanced frequency source is a single chamber source and thus can be treated as a point source. This significantly simplifies many processing steps as there is no angular or azimuthal variation of the source, other than standard source ghost effects. In Figure

2 we can see the extracted source signatures of the standard air gun array and the enhanced frequency source for shots with source take-off angle of 50 degrees and source-receiver azimuths every 90 degrees. From these examples we can see the signature of the point source is stable across all azimuths. Being a point source, the signature will be consistent not only at all azimuths, but also at all take-off angles. An angularly isotropic source will significantly simplify many processing steps such as source designature and zero phasing, which become a 1-D operator. A single wavelet can also be used as the target wavelet for FWI forward modelling, knowing that at high angles and azimuths there will be no deviation from the vertical wavelet, thus reducing noise and uncertainty in the inversion results.

The vertical source wavelets were extracted from traces with less than ten degrees of vertical angle, their amplitude spectra are shown in Figure 3. The enhanced frequency source has a peak frequency near 3.5 Hz, compared to 7 Hz with the standard air gun array. At low frequencies the source generates more than 6 dB additional energy than standard arrays, the amplitude spectrum also remains relatively flat up to 45 Hz. The near field hydrophone data was also used to investigate the ultra-high frequency energy generated by the two sources. At frequencies above 800 Hz, the enhanced frequency source produces 32 dB less energy than the standard air gun array. This is a significant reduction in marine mammal impact, in addition the overall Sound Exposure Level (SEL) and Sound Pressure Level (SPL) are lower.

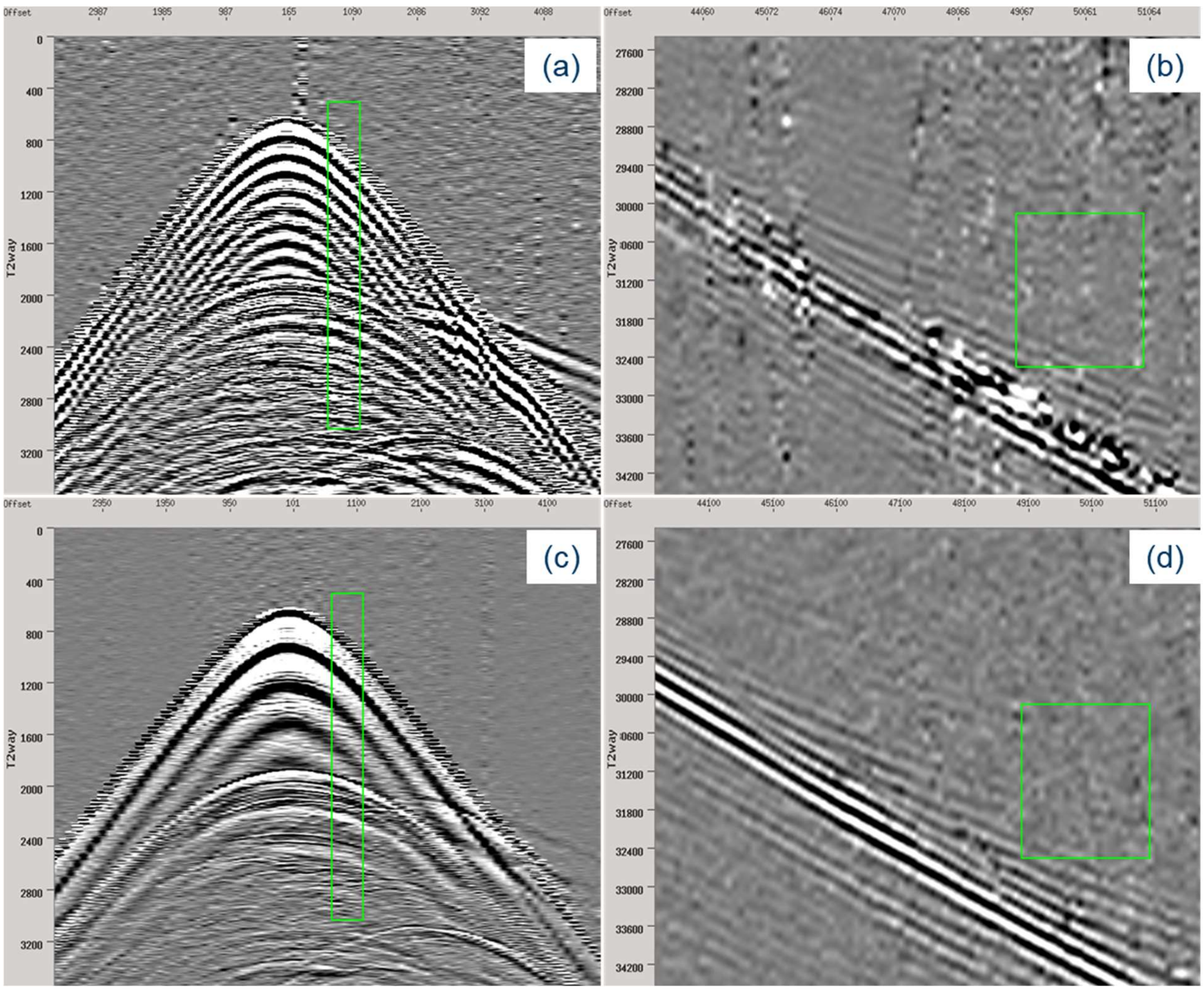

Figure 1 – Single OBN gather illustrating standard air gun array near offset (a), long offset (b), and enhanced frequency source near offset (c) and long offset (d). The long offset display is showing offsets from 43 km to 53 km.

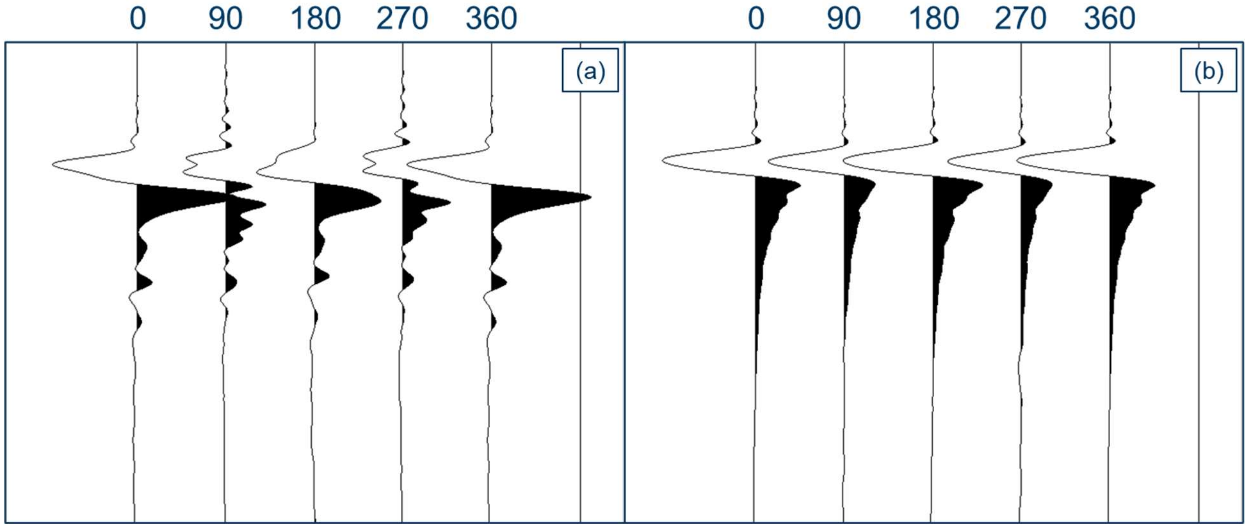

Figure 2 – Source signatures extracted from node data at 50 degree take-off angle. Source to receiver azimuth, relative to source vessel direction, is shown above the wavelets. Notice the variability in source signature on the standard air gun array (a), and the stability of the source signature on the enhanced frequency source (b).

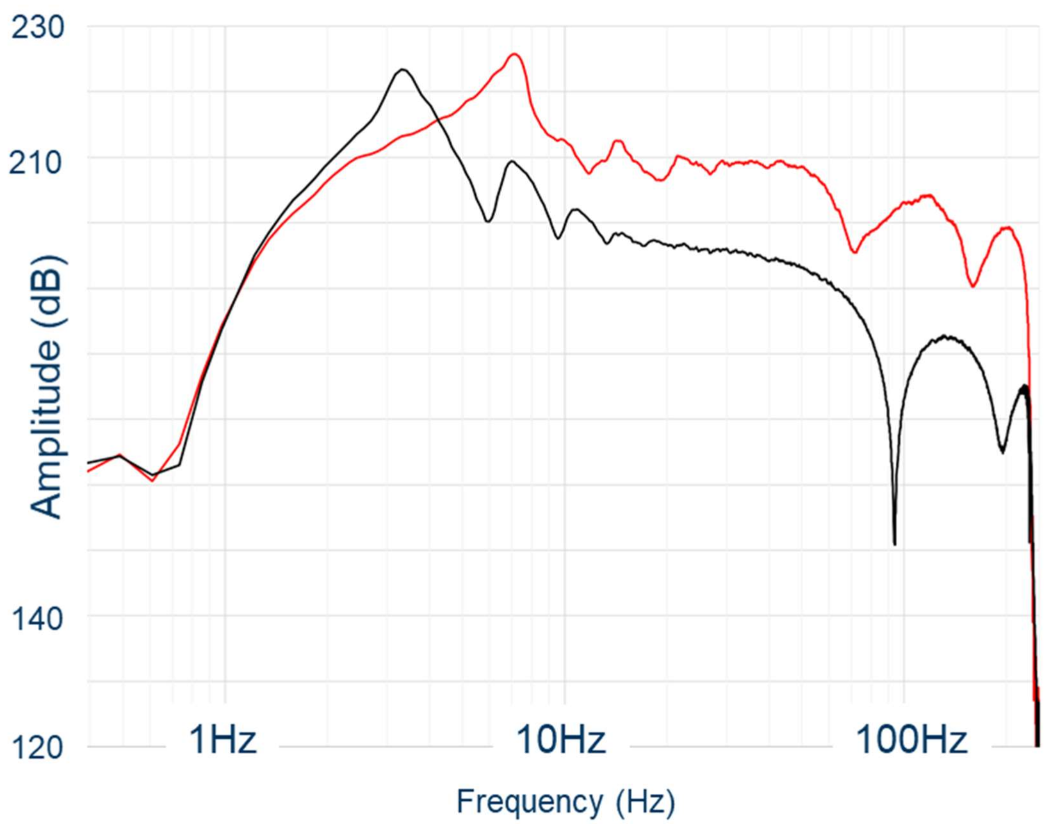

Figure 3 – Amplitude spectra extracted from vertical source wavelets of standard air gun array source (red) and the enhanced frequency source (black). The node instrument response has been removed, and we can see significantly more low frequency energy from the enhanced frequency source, with a relatively flat spectrum up to about 45 Hz.

A broadband model building and imaging source

Conclusions

The enhanced frequency source satisfies many current and future requirements within marine acquisition and imaging: generating more low frequency energy, and typical imaging frequencies with a significant reduction in ultra-high frequencies. This will improve FWI and imaging of the subsurface while reducing the impact on the environment and marine life. The source is a point source, which is beneficial to multiple processing steps. As surveys are acquired with increasingly long offsets and richness in angle and azimuth, signature stability at high angles becomes crucial for long offset full azimuth FWI. An angularly isotropic source will match FWI forward modelling better at all angles, resulting in lower noise and uncertainty in the derived velocity model.

Operationally the source has shown less downtime than standard air gun sources as there are less components that can fail, and the source can be quickly replaced by bringing in a single string. This is operationally safer and simpler than with standard air gun sources. The source has been used in multiple surveys with very good uptime and source signature repeatability.

Acknowledgements

The authors would like to thank TGS, and partner SLB, for permission to show data and analysis from the Engagement 1 OBN survey. We would also like to thank our colleagues for many engaging discussions relating to point sources and low frequency sources.

References

Dellinger, J., Ross, A., Meaux, D., Brenders, A., Gesoff, G., Etgen, J., Naranjo, J., Openshaw, G., and Harper, M. [2016] Wolfspar®, an “FWI-friendly” ultralow-frequency marine seismic source. 86th Annual International Meeting, SEG, Expanded Abstracts, 4891-4895. https://doi.org/10.1190/segam2016-13762702.1

Tenghamn, R., Mattsson, A. [2022] A very low frequency marine vibrator. Third EAGE Marine Acquisition Workshop, Aug 2022, Volume 2022, p. 1-3. https://doi.org/10.3997/2214-4609.202242003

Hopperstad, J.-F., Laws, R. and Kragh, E. [2012] Hypercluster of airguns: More low frequencies for the same quantity of air: 74th Annual International Conference and Exhibition, EAGE, Extended Abstracts, Z011. https://doi.org/10.3997/2214-4609.20148845

Willis, H., [1941] Underwater explosions, time interval between successive explosions: Technical report, British Report WA-47-21