Submission code: N0PXAKV70R

See this and other abstracts on our website: https://home.sbgf.org.br/Pages/resumos.php

Ultrashallow imaging using active and passive near-field hydrophones measurements

Frederico Xavier de Melo (SLB), Mina Matta (SLB)

Ultrashallow imaging using active and passive near-field hydrophones measurements

Abstract

We present an ultrashallow reflectivity reconstruction method by integrating active and passive near-field hydrophone (NFH) measurements via a matching pursuit algorithm. This technique aims to create a detailed three-dimensional (3D) image of the shallow subsurface, focusing on the water bottom and near-surface reflectivity interval that are often not recorded by conventional towed-streamer acquisition methods.

One application of the information we can retrieve from NFH measurements is to provide auxiliary near-seafloor images that can be combined with existing methods and approaches that rely or require reliable information of ultrashallow events present in the seismic experiment, not captured by the conventional towed-streamer acquisition configuration.

Introduction

Any 3D seismic experiments using towed-streamer configurations are challenged by operational constraints in shallow and ultrashallow waters, resulting in unresolved and poorly illuminated near-seafloor formations. In areas with water depths shallower than 50 m, early arrivals often come from postcritical events, which are considered coherent noise masking specular and acoustic energy from shallow reflectors. This issue is exacerbated in limited near offsets and small angle coverage settings, where even channels closer to the source locations may fail to capture near-surface reflections. This problem is amplified with wider-towed acquisition configurations, where the lack of properly recorded information impairs processes depending on reliable near-seafloor measurements.

Near-field hydrophones (NFHs) are receivers placed above each airgun array, in addition to those along the streamer cable. Often used as a quality-control tool to monitor the state of health of the firing sources, NFHs can record data that we categorize as active and passive records. Active NFHs are positioned above arrays during firing and intentionally record the source event. In contrast, passive NFHs can record useful near-offset information about the subsurface. Traditionally, NFHs have been employed for source designature (Ziolkowski and Johnston, 1997), shallow imaging (Tyagi et al., 2021; 2022), and fine-tuning velocity models.

In this work we propose an integrated approach over the Sarawak basin (Khor et al., 2024) by combining active and passive NFH measurements via a matching pursuit scheme (Bilsby et al. 2023). The main goal is to construct a shallow 3D image, providing detailed information about the water bottom and near-surface reflectivity not captured by standard towed-streamer acquisition geometries. The near-seafloor images derived from the proposed method can be combined with existing methods and approaches that rely or require reliable information of the ultrashallow events present in the seismic experiment and not captured by the conventional towed-streamer acquisition configuration.

Methodology and Results

The workflow is composed of two independent steps: Phase 1 involves reformatting, auditing, and signal processing of active and passive NFH measurements, while Phase 2 focuses on merging these measurements and reconstructing the near-seafloor images.

Hydrophones positioned close to seismic sources, such as airguns, vibrators, or other mechanical devices, are designed to capture near-field acoustic signals generated from these active sources. NFH measurements are categorized into active and passive recordings (Figure 1). The former refers to hydrophones located directly above the firing source, while the latter pertains to those positioned above inactive sources but still recording acoustic events. This approach allows the collection of acoustic data at nearly zero offset, generally compromised by the strong noise and bubble reverberations resulting from the proximity to the active source.

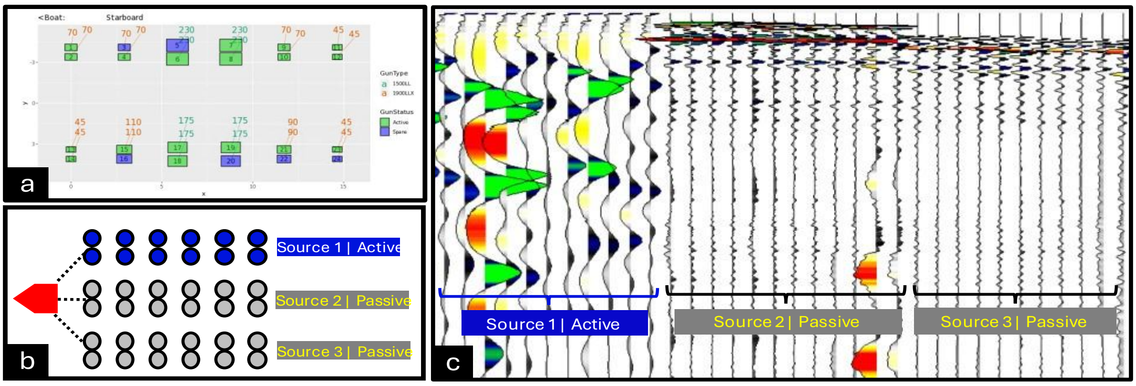

Figure 1: Source configuration. (a) Single gun-array setup, (b) Schematic of triple sources with active (blue circles) and passive (grey) sources, and (c) Raw NFH recording for a single shot illustrating both active and passive measurements.

The first step is a complete analysis of both active and passive NFH measurements to assess the geometry and feasibility of the recorded water-bottom and near-surface information. This stage also characterizes features pertinent to each measurement, such as noise content and intensity of bubble pulses. Each measurement undergoes various signal processing steps, including adaptive source signature attenuation (ASSA) and random noise attenuation.

Given the presence of strong bubble pulses in the active NFH measurements, a gun-by-gun driven debubble operator is estimated and matched before being adaptively subtracted from the noise-attenuated NFH data. Due to the superior signal-to-noise ratio (SNR) of the passive NFH measurements compared to the active NFH, the passive measurements are used in the noise attenuation and debubble steps to ensure stability and consistency of the results between the two types of measurements using stacked signature crosscorrelation. Adaptive deghosting is then applied to attenuate both source- and receiver-side ghosts (Rickett et al., 2014), followed by multiple energy prediction and attenuation, resulting in a broader amplitude spectrum and multiple-free NFH data. Figure 2 shows an example of the data for each component, before and after the full preconditioning applied.

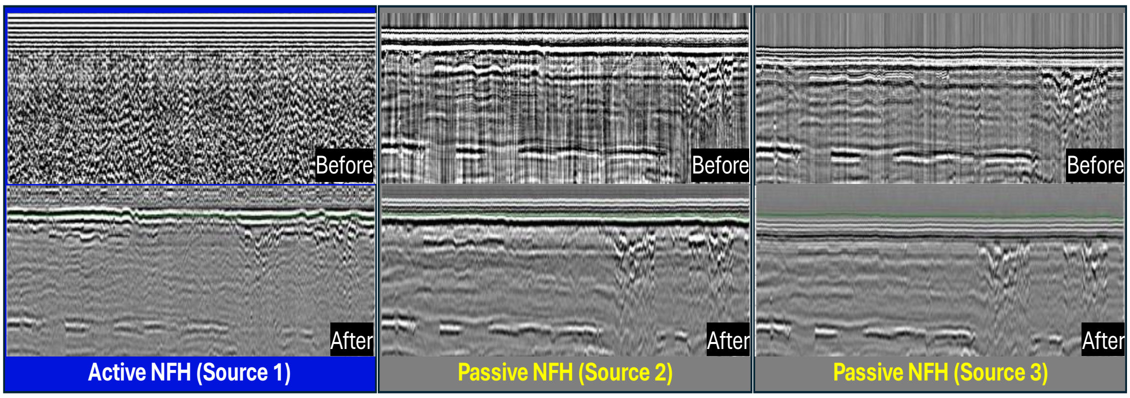

Figure 2: Raw active and passive records for a sail line before (top) and after process (bottom).

A frequency-dependent stacking process is applied to match the processed measurements into a single dataset. This ensures the retention of low-frequency components from the passive NFH and high-frequency components from the active NFH in regions characterized as having low SNR.

The integrated NFH data are used as input to construct a 3D volume using a multistage matching pursuit reconstruction process, employed to produce an adequate subsurface representation of the measurements required for near-seafloor imaging. The imaging step consisted of a high-resolution Kirchhoff depth migration (KDM), followed by image enhancement processes, such as acquisition footprint attenuation. Figure 3 shows the comparison between a KDM image of the nearest offset of the streamer data and an image of the NFH using the same migration algorithm and parameters. The NFH reconstructed image, particularly in the regions above the top unconformity, exhibits significantly higher resolution and enhanced definition.

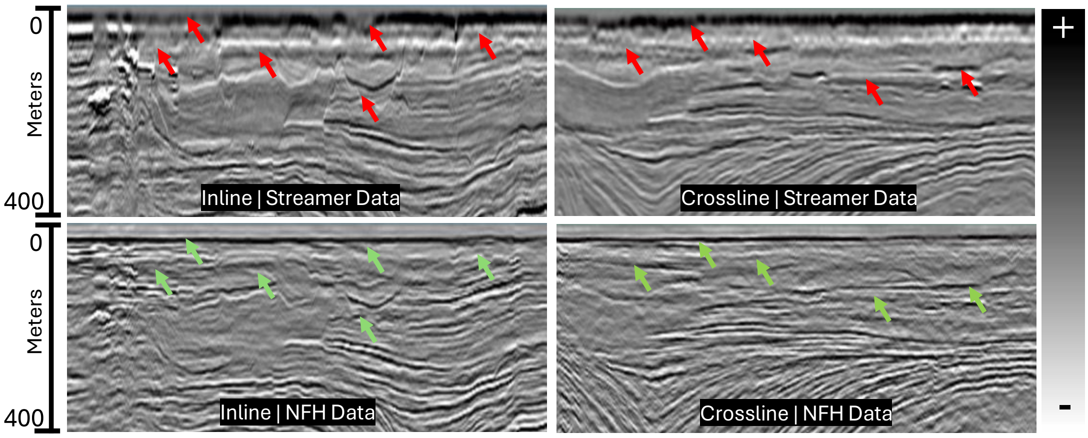

Figure 3: KDM image of streamer data versus NFH data, inline (left) and crossline (right). Top displays show the nearest offset at 200 m of processed streamer data, while bottom displays show the reconstructed active and passive NFH image. Green arrows point to areas with improved definition relative to the red arrows displayed on the streamer data.

We can further validate the improved near-seafloor response obtained from the proposed approach when comparing the streamer and NFH images from a 3D perspective. Figure 4 shows a continuous and high-resolution response of the NFH output starting from the ultrashallow seafloor with an average depth of 20 m.

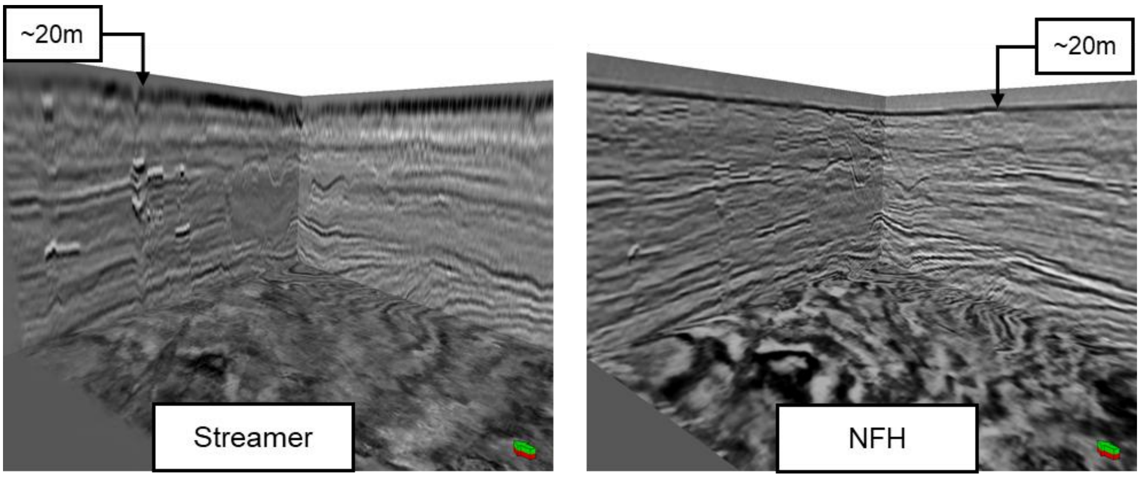

Figure 4: 3D view comparison between the KDM image of streamer (left) versus NFH (right). The average water depth is about 20 m, showing higher resolution and a better focused near-seafloor response obtained with the NFH in comparison with the stretched response from the streamer.

The near-seafloor images derived from the proposed method can be combined with existing techniques to act as a proxy model when deriving deterministic operators. One practical application is constructing deterministic operators that can be used as input in different parts of the processing workflow, such as multiple attenuation and primary avoidance weights in different coherent suppression components.

Conclusions

In this study we demonstrated the effectiveness of using active and passive NFH measurements when retrieving and reconstructing the near-seafloor response. Combined with a multi-stage interpolation approach, we were able to construct a dense and reliable representation of the ultrashallow interval of the subsurface, allowing us to overcome the challenges and limitations of a sparse cable towed-streamer acquisition in such environments.

The tailored pre-processing and integration of these measurements through an assertive approach allied with a matching pursuit scheme, enables constructing detailed shallow 3D images, significantly enhancing our ability to produce and visualize shallow subsurface images that can be used as auxiliary information across different segments of the seismic processing workflow. One straightforward application is the usage of these measurements as auxiliary information when addressing surface-related multiple contamination in challenging shallow-water environments, ultimately improving the accuracy and reliability of the existing workflows.

Acknowledgments

The authors thank the management of SK Earthon, Malaysia Petroleum Management (MPM), Petroleum Sarawak Berhad (PETROS), and SLB for permission to publish this work, and the SLB Geosolutions team. Extended thanks to Dr. Young Kim.

References

Bilsby, P., Kumar, R., Vassallo, M. and Zarkhidze, A. [2023]. Multistage matching pursuit Fourier interpolation with physics-based priors.84th EAGE Conference and Exhibition, Expanded Abstracts.

Khor, M., Choi, H., Lee, K., Jeong, C. H., Nor, N. M., Ong, S. W., Ismail, M. A., Zolkipli, I. H. and Ting, T. M. [2024]. 3D Marine Seismic Survey in Operationally Marginal Shallow Water off the coast of Sarawak, Malaysia. Asia Petroleum Geoscience Conference & Exhibition 2024, Extended Abstracts.

Rickett, J., Van Manen, D.-J., Loganathan, P. and Seymour, N. [2014]. Slanted-streamer data-adaptive deghosting with local plane waves. 76th EAGE Conference & Exhibition, Extended Abstracts, Th LI115.

Tyagi, C., Leake S., Mistry K., Olsen C. and Sundøy K. [2021]. Utilizing near-field hydrophone data for high-resolution shallow hazard imaging. 83rd EAGE Annual Conference & Exhibition, Extended Abstracts.

Tyagi, C., Xu, H., Ferriday, M., Riley, G., Gomes, J., Bovet, L., Brunelliere, J. and Sioni, S. [2022]. Regional 3D near-field hydrophone imaging: Adding value to dense OBN acquisition from offshore Arabian Gulf. 83rd EAGE Annual Conference & Exhibition, Extended Abstracts.

Ziolkowski, A. and Johnston, R. [1997]. Marine seismic sources: QC of the wavefield computation for near field pressure measurements, Geophysical Prospecting 45, 611-639.