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Scholte wave analysis of Libra OBN passive data

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Summary

Seismic interferometry studies have increasingly leveraged Ocean Bottom Node (OBN) arrays over the past decade to utilize low-frequency microseism energy. This approach has enabled researchers to effectively extract Scholte waves, which are critical for performing shear wave inversion. The Libra OBN survey's quiet period was characterized by abundant energy in the microseism frequency range of 0.1 to 1.75 Hz. Using spectrogram analysis, we identified an optimal microseism window for interferometry. Within this window, pre-processing and cross-correlation were applied to generate virtual source gathers (VSGs). The VSGs exhibited clear Scholte-wave dispersion, enabling high-quality dispersion images with multiple modes suitable for inversion. We then extracted the fundamental mode to pick the dispersion curve and perform shear-wave velocity inversion.

Introduction

The long, continuous recordings characteristic of Ocean Bottom Node (OBN) surveys unlock a wealth of seismic information that extends beyond conventional active source data. A particularly valuable and readily available resource within these recordings is low-frequency ambient noise, known as microseisms (0.1-1.75 Hz) (Longuet-Higgins, 1950). This inherent seismic energy offers a compelling and cost-efficient pathway to explore subsurface architectures using advanced imaging techniques. Ambient seismic energy, generated by oceanic processes like swell-induced gravity waves, transfers wave-field energy into the subsurface. This energy predominantly propagates as surface waves, with frequency-dependent characteristics influenced by the elastic properties of the solid medium and the acoustic properties of seawater (Girard et al., 2024). Over the last decade, seismic interferometry studies have increasingly utilized the response of OBN to this low-frequency microseism energy. Notably, researchers have successfully retrieved usable Scholte-wave for shear wave inversion (de Ridder and Dellinger, 2011,Dong et al., 2021 and Girard et al., 2024).

This paper investigates the feasibility of applying ambient noise interferometry to construct virtual shot gathers (VSGs) from microseisms utilizing data from the 2018 OBN survey in the Libra field (Figure 1). To mitigate the low-frequency distortion inherent in OBN sensors, pre-processing techniques are applied applied prior to the seismic interferometry (Bensen et al., 2007 and Girard et al., 2024). Interestingly, a two-month pause in active seismic operations, during what was primarily an active source survey, provided an opportunity to examine the ambient microseism wave field. The insights gained from the analysis of these data are directly relevant to the planned deployment of a Permanent Reservoir Monitoring (PRM) system in Libra in the following year.

Libra OBN Survey

The OBN deployment for the Libra survey consisted of multiple Ocean Bottom Nodes (OBNs) arranged in a non-staggered grid with a uniform 500-meter inter-node spacing in both the inline and crossline directions. Passive seismic analysis in this study utilized a subset of the recorded data acquired during periods of no active source activity. The spatial distribution of the OBNs that recorded data during these passive listening periods is illustrated in Figure 1 (red markers). To determine the most suitable period for microseism energy analysis, we computed spectrograms from the hydrophone recordings of representative OBNs (for instance, one of those marked by a white dot in Figure 1). We utilized the hydrophone component continuous 59-day pressure time series, $p(t)$ and initially processed with an anti-alias filter and subsequently down-sampled to a 100 ms sampling interval to reduce data volume. Following this, the Power Spectrum Density (PSD) was estimated using 60-second segments of the time series, employing a Hann window to minimize spectral leakage from the window edges.

The computed spectra were displayed side by side (Figure 2) to visualize their temporal variations. This analysis revealed a consistent presence of energy within the low-frequency range (0.1-1.75 Hz) of the OBN recordings, identified as microseism ambient noise generated by weather conditions. This allowed us to select the optimal microseism window for subsequent interferometry.

Methodology

The methodology of seismic interferometry allows us to retrieve inter-station Green's functions from ambient seismic recordings through cross-correlation. Our approach involved selecting the seismic trace from a particular OBN as a master reference. We then cross-correlated this master trace with the traces from all other OBNs within the previously defined optimal time window. This effectively simulates a seismic source at the location of the master station, resulting in a Virtual Shot Gather (VSG).

Recognizing the potential for phase distortions and signal attenuation below 3 Hz due to the hydrophone's frequency response, we implemented possibilities of pre-processing sequence – detrending and band-pass filtering – to be applied prior to performing the cross-correlations. Additionally, to ensure the integrity of the correlation process, we applied a time shift to each OBN recording to achieve precise temporal alignment across the entire array. In order to analyze the dispersive behavior of the Scholte-type surface waves, we employed the Multichannel Analysis of Surface Waves (MASW) tool (Olafsdottir et al., 2024) to generate its dispersion image and pick the dispersion curves to carry out the inversion.

Results

The Virtual Shot Gather (VSG), derived from the interferometry of line 1281 (yellow nodes lines, Figure 1), clearly displays surface wave propagation and is shown on the left side of Figure 3. The corresponding computed dispersion image, which illustrates the phase velocity as a function of frequency, is presented on the right side of Figure 3. This image reveals the presence of the fundamental mode as well as five higher modes.

Although the primary focus of this paper is on generating Virtual Shot Gathers (VSGs) and their corresponding dispersion images - rather than conducting a comprehensive inversion study - we provide an illustrative inversion example using the dispersion image from Figure 3. The clarity and quality of the dispersion image are crucial for accurately picking the dispersion curves. The Figure 4 presents, at left, a zoomed-in view of the fundamental mode used to pick the dispersion curve. On the right side of the Figure 4, the inverted dispersion curve (plotted in blue) is compared with the theoretical Scholte-wave dispersion curve. The optimal subsurface parameters were determined by iteratively minimizing the difference between the theoretical and observed Scholte-wave dispersion curves. The most sensitive parameters (Shear-wave velocity (Vs) and layer thickness) are shown in the table on the right side of Figure 4.

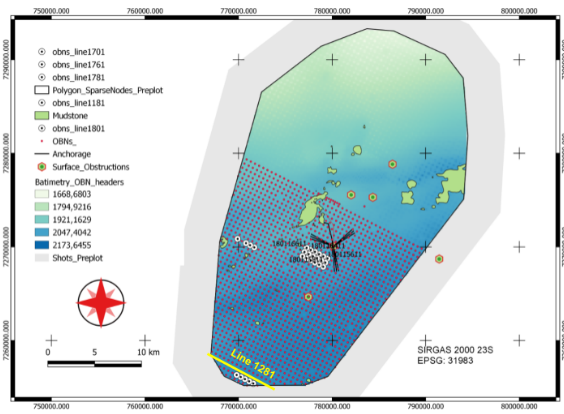

Figure 1: Map of the Libra 2018 OBN survey.

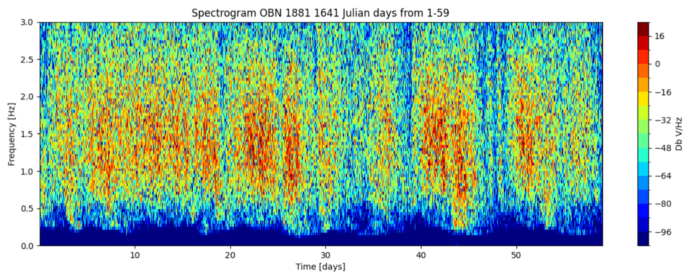

Figure 2: Spectrogram along 59 days indicating the 1-3 Hz microseism energy content.

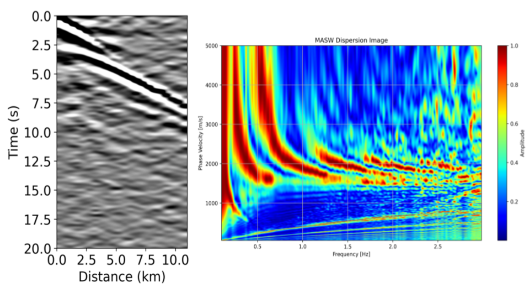

Figure 3: VSG on Line 1281 and its MASW dispersive image.

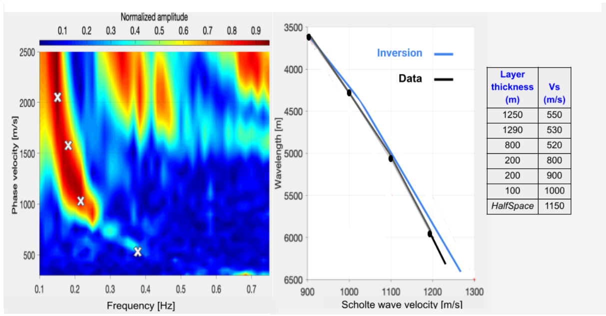

Figure 4: Fundamental mode of Line 1281, picks and inversion from theoretical Scholte wave.

Conclusions

The Libra OBN data exhibits abundant microseism energy within the 0.1 to 1.75 Hz frequency range, suitable for passive seismic analysis. Seismic interferometry successfully generated Virtual Shot Gathers (VSGs) that clearly display Scholte-type surface waves with sufficient quality to produce robust dispersion images for curve picking. Furthermore, the Scholte wave inversion of the picked fundamental mode dispersion curve effectively retrieved shear velocity information for velocity model construction.

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