3D Ultra High Resolution seismic processing – A case study from Offshore USA

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Summary

A 3D Ultra High Resolution Seismic (UHRS) survey was initiated in the summer of 2023, offshore USA. The survey, utilizing a P-Cable system, covers an expansive area very efficiently. The near-surface stratigraphy, ranging from the Miocene to the Holocene, provides a geological context challenging for effective site characterization.

The processing workflows for 3D UHRS data, although sharing similarities with conventional seismic processing sequences, require enhancement due to significant scale differences. High-Performance Computing (HPC) resources are vital for processing the high-density and small-sampling-rate 3D UHRS data. Key steps include achieving a broadband wavelet via data-driven deghosting and designature techniques. Accurate statics computation addresses challenges arising from sea state variations, ensuring clear and sharp reflections. The demultiple step, utilizing methods like convolutional 3D Surface Related Multiple Elimination (SRME) and 3D wave-equation multiple modeling, effectively removes unwanted reverberations, providing a cleaner seismic dataset.

While the acquisition and processing are ongoing, preliminary post-stack time migration results provide a continuous 3D volume with high vertical and spatial resolution. The 3D aspect provides an invaluable platform for interpretation, small features detection, shallow geohazard investigation, and quantitative analysis.

Introduction

With ambitious targets being set for offshore wind globally, full lease area coverage of 3D UHRS data can be implemented to expedite the development of wind farms. This paper focuses on enhancing seismic processing workflows to maximize the use of 3D UHRS data, ultimately leading to an improved and quicker site characterization.

In the summer of 2023, a groundbreaking 3D UHRS acquisition survey was initiated to gather seismic data utilizing a P-Cable system (MacGregor et al., 2022), comprising 8 x 100 m streamers. The innovative P-Cable system incorporates a perpendicular cable (cross cable) at the front of the spread, connecting all streamers with a separation of 12.5 m. This design ensures stable crossline sampling, particularly effective when coupled with a wide-tow triple source configuration (Widmaier et al., 2019). The acquisition bin size is 1.56 m x 2.08 m in subline and crossline directions, respectively. Three seismic sources in the form of dual-stacked Sparkers are strategically positioned above the front of the streamer spread, minimizing the radial distance to the first offset class. The temporal sampling interval of 0.125 milliseconds corresponds to a Nyquist frequency of 4 kHz.

This acquisition design makes the survey very efficient as 24 subsurface lines are simultaneously acquired during the passage of 1 sail line. This allows the 3D survey of about 500 sqkm to be acquired in a single campaign. Throughout the ongoing acquisition phase, raw shot gathers are continuously transmitted to the onshore processing data center via satellite links. This real-time data streaming empowers the processing team to promptly develop and apply optimized processing workflows, commencing right from the initiation of the acquisition survey.

The near-surface stratigraphy (within the first 100 m below seabed) of the study area encompasses a geological timeline ranging from the Miocene to the Holocene. It is characterized by successions of fluvial, estuarine and shallow marine depositional environments. This comprehensive geological context provides a foundational understanding for the subsequent analysis and interpretation of the acquired seismic data in the pursuit of effective wind farm site characterization.

Processing workflows

The processing workflows for 3D UHRS data share similarities with those established for 'conventional' seismic methods used in Oil & Gas exploration. However, notable distinctions arise due to the several orders of magnitude difference in scale concerning the recorded data, both spatially and temporally. Consequently, there is a need to enhance 3D UHRS processing workflows to effectively handle the high frequencies and spatial density. It is important to highlight that significant High-Performance Computing (HPC) resources may be requisite for processing 3D UHRS data due to its high density and small sampling rate.

In the initial stages of signal processing, achieving a broadband wavelet is crucial to maximize resolution and recover fine stratigraphic details and small-scale features. This involves receiver-side and source-side deghosting, followed by designature, including zero-phasing. Notably, removing receiver ghosts presents a substantial challenge due to the very high frequency content and variations in receiver depth. The data-driven inversion-based deghosting methodology becomes essential, estimating receiver depths and suppressing ghosts in local time-slowness windows. Source-side deghosting, on the other hand, encounters fewer challenges as Sparker units are suspended to a floating device, maintaining stable depth by naturally following the sea surface.

Source signatures are estimated on a shot-by-shot basis thanks to high-order statistics, as described by Bekara (2021). This method offers the advantage of not requiring alignment to the water-bottom reflection, particularly challenging in the presence of sea surface statics. The designature process involves shaping each signature to a common desired broadband zero-phase wavelet, removing variations between sources, shots, and sail lines. Additionally, a source directivity compensation is applied using modeled notionals, resulting in enhanced resolution and simplified geological features. Figure 1 shows the successive changes associated with applying receiver deghosting, source deghosting and designature. The latter shows a clear broadening in signal bandwidth.

The computation of statics becomes more accurate with clearer and sharper reflections peaks. Static issues arise due to sea state variation. Static corrections, estimated using water-bottom reflections against simultaneous multibeam echosounder data (MBES – bathymetry data acquired using the same seismic vessel) and receiver depth values estimated from the deghosting step, compensate for sea surface variation. After applying statics, the data is redatumed to the same reference datum as the bathymetry data. This process also takes into consideration the time variations due to tides.

Figure 2 shows the water bottom has become a smooth and flat event after the application of the sea surface statics.

Demultiple, a crucial step in seismic pre-processing, employs various methods, including convolutional 3D Surface Related Multiple Elimination (SRME) and 3D wave-equation multiple modeling (Barnes et al., 2015). These methods produce accurate multiple models, simultaneously adapted and subtracted. Compensating for sea surface statics poses a challenge during the subtraction step. Multiples are further affected by free surface effects in a nonlinear way compared to their corresponding primary events. The adaption process was tuned by allowing for larger time shift corrections in relatively larger windows. The pre-migration demultiple step effectively removes water bottom reverberations and pegleg multiples, even in noisy areas with weak primary signals, as illustrated in Figure 3.

A tailored series of denoise steps taking advantage of the 3D geometry has allowed to increase the signal to acceptable level allowing for the interpretation of the deeper sediments.

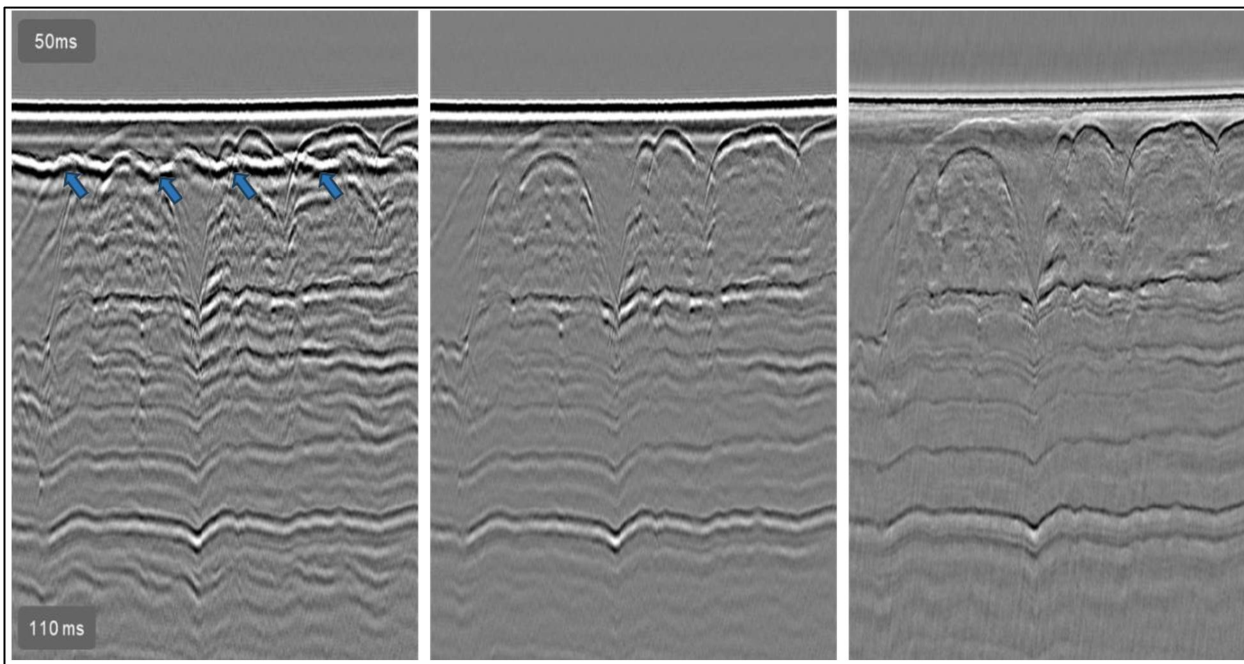

Figure 1: 2D unmigrated stacks after denoise (left – blue arrows pointing to the receiver ghosts), after receiver deghosting (centre), and after source deghosting + designature (right). Statics were applied to all displays for comparison only

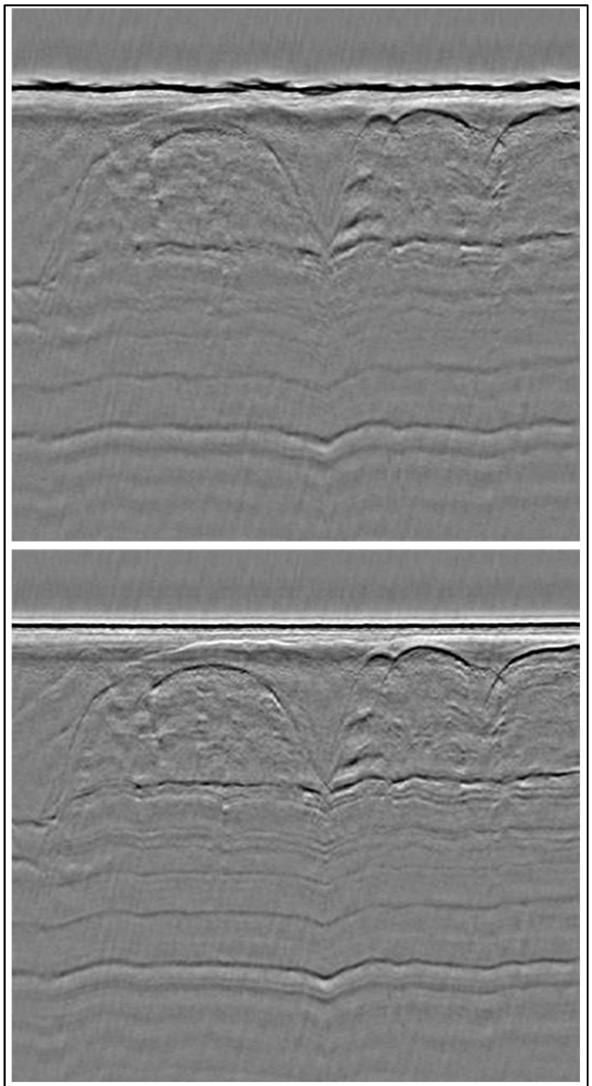

Figure 2: 2D unmigrated stacks after designature (top) and after sea-state statics (bottom).

Preliminary results

At the time of writing this abstract, the acquisition and processing is still ongoing. It is expected that the final results will be available and shared at IMAGE24. Meanwhile, a preliminary post-stack time migration image, which encompasses wavelet processing, statics correction, and demultiple processes, is shown in Figure 4. This earlier-out product is accumulated while the acquisition is ongoing. It allows for the time-consuming interpretation works to start almost immediately after the start of the acquisition. The 3D nature of the dataset allows for clear identification of the geological features expected in the survey area, as such as channels as shown on the time slice. The initial interpretation enables identification of the main soil units. An amplitude spectrum analysis indicates that the useful signal extends up to 3 kHz. The early-out and final 3D products serves/will serve as an invaluable platform for the interpretation framework, detection of small objects, and potential for quantitative analysis.

Additionally, the preliminary results show areas with low illumination and pull-up and pull-down features due to shallow velocity anomalies. These challenges underscore the complexity of the near surface geology, indicating the need for more advanced depth processing technology such as Least Squares Migration and Full Waveform Inversion.

Conclusions

In conclusion, this work focuses on optimizing seismic processing workflows for a novel 3D UHRS acquisition survey, acquired offshore USA. Key processing steps need to be carefully tuned to enhance the ultra high resolution nature of the recorded data. Data-driven techniques should be privileged to correct for the impact of the sea state variability. The early-out product allows the interpretation to start while the acquisition is progressing. Preliminary results demonstrate a dataset rich in vertical and spatial resolution, showcasing the high potential for interpretation, small object detection, and quantitative analysis. The preliminary results also show that more advanced depth technologies could bring benefits to the migrated image.

The integrated approach of a single campaign acquisition, processing and interpretation provides an effective way of accelerating the wind farm development projects.

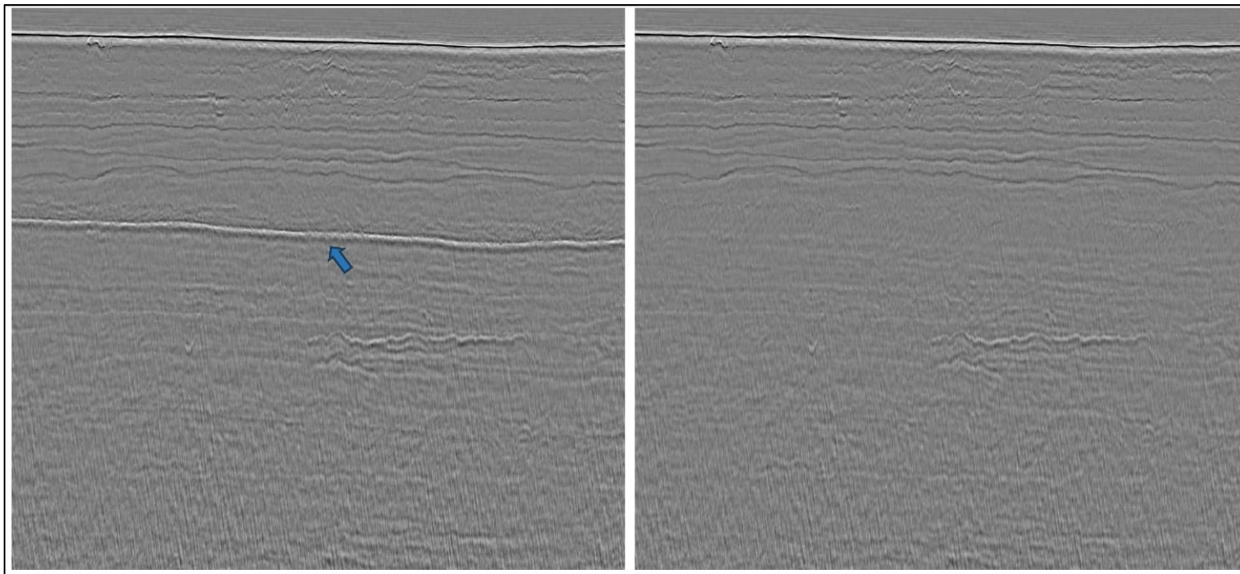

Figure 3: 2D migrated stacks before (left), after demultiple (right), The blue arrow points to the first bounce multiple of the seabed.

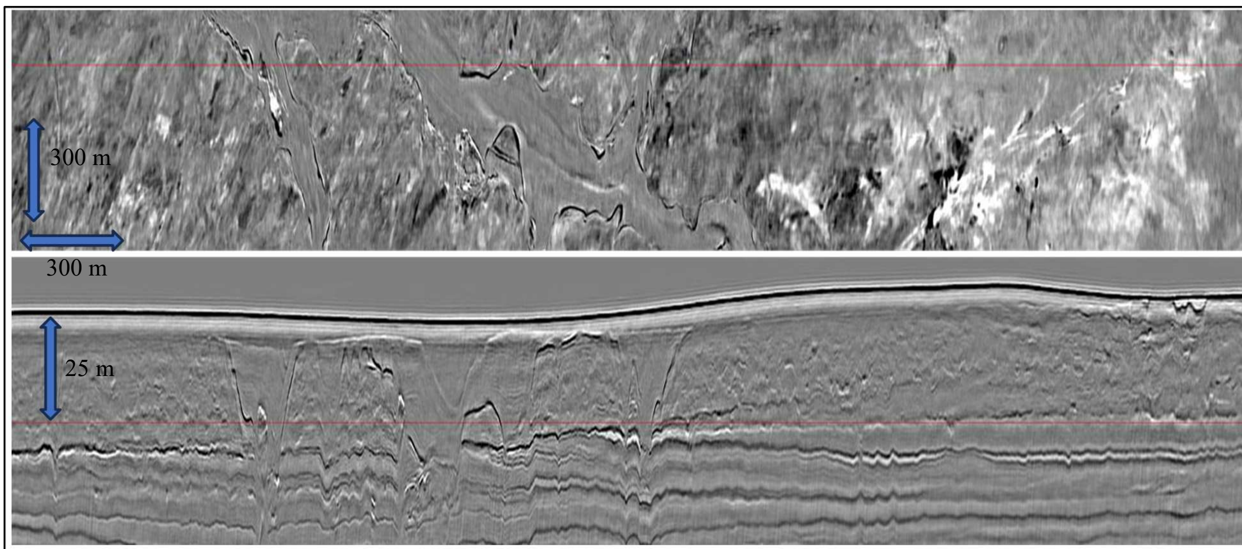

Figure 4: 3D preliminary post-stack time migration cube. On top, it is a timeslice around 25 m below seabed. At the bottom, a cross-section.