Designing surveys in an updated regulatory environment – with consideration of processing

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Summary

Updated regulations for seismic surveys acquired in the Gulf of Mexico have significantly changed how large scale Ocean Bottom Node (OBN) surveys can be acquired. The primary impact of these changes is a limitation in the time source boats can be actively using air gun arrays. To acquire a commercially viable sparse OBN survey, source vessels with 100 m crossline separation triple source will have to sail faster. There was uncertainty from source vessel contractors, due to having never operated wide tows at significantly increased speeds, about the ability to maintain source separation within survey specifications. Prior to the start of a sparse OBN survey, a series of more complex and realistic models were generated to test the key processing steps. Acquisition parameters that were modified included source spread width, water current variations, blending dither patterns, and source vessel separation distances. The results of the tests led to modifications of the acquisition parameters prior to the start of the survey and increased confidence in the ability to process a survey with new requirements and parameters.

Introduction

Recent updates to regulations regarding marine seismic acquisition require rethinking acquisition parameters and survey designs. In the Gulf of Mexico there is now an effective sixty-five day limit on active source time per survey and limitations on minimum time between shots on a given vessel, in order to prevent marine mammal disturbances. To acquire large scale sparse node surveys within the new limits, source vessels must sail faster than in previous surveys. Sailing faster significantly increases forces on subsea equipment and towing gear, which increases uncertainty in achieving specified spread width of typical triple source towing configurations. Prior to beginning a multi-client sparse node survey, a modelling exercise was performed to determine the acquisition limits where the final survey quality would be impacted.

Method

In order to acquire the planned survey, source vessels are required to average 5.1 knots for the duration of the active source effort. Increased vessel speed, with the desire to have wide tow triple source acquisition significantly increases the forces on subsea towing equipment. The source vessel operators were uncertain in the ability to maintain a 200 m spread width, from 100 m source separation and triple source, possibly limiting spread width down to 160 m. Time limitations, due to updated federal regulations, removes the option of adding additional source lines needed for regular crossline source separation throughout the survey. To increase the amount of sail line kilometers that could be acquired within the time constraint, with the belief that inline source spacing was not required to be consistent for this survey, the sources would be fired on time rather than on location. Shooting on location requires the source vessel to slow down in when surface currents are moving in the direction of vessel travel. Shooting on time, while maintaining consistent speed through water causes variation in inline shot sampling in the presence of surface currents.

Key processing stages to evaluate the effects of variability of both source line spacing variability, and inline shot sampling variability were identified. The processing steps tested were deblending, interpolation/regularization, and Full Waveform Inversion (FWI). A series of increasingly complex models were generated to test the various processing steps. The initial model was a single node gather modelled with flat reflectors and point diffractors. An acoustic forward model, using the final FWI velocity model from a nearby sparse OBN survey, was generated to cover 300 node locations in a 30 km by 30 km shot patch. The shot patch was modelled to have consistent inline shot sampling with variable crossline sampling on half of the shot patch, simulating the potential changes of the spread width from tow forces. The other half was modelled with constant crossline spacing and variable inline source sampling, simulating the effects of shooting on time with various surface current conditions. All source vessel speeds modelled were maintained at 5.1 knot through water.

Examples

Regularization and interpolation successfully reconstructed the subsurface model, even from the most irregular source sampling modelled. Figure 1 shows a time slice through a modelled node location before and after regularization of the source grid. In Figures 1e and 1f, diving waves, reflected waves, and the direct arrival are all clearly reconstructed from the irregular grid caused by spread width (Figure 1b) and currents (Figure 1c). Source vessel direction was identified to be recommended to be in opposite directions on neighboring vessel passes in areas with stronger currents. Sailing in opposite directions when surface currents are strong will ensure that local source spatial density will remain near the desired level.

After ensuring interpolation and regularization can reconstruct the data with the full suite of source spacings, many styles of blended acquisition were modelled and deblended. Dither size and distribution were tested, with consideration of Jiang's Limit (Jiang and Abma, 2010). The primary intent of the survey is to produce a high fidelity FWI velocity model beginning at the lowest possible frequency. Deblending and wavelet tests showed a plus-minus 500 ms dither was sufficient for frequencies down to 1 Hz. Dither distributions that were tested included flat dither distributions, flat dither difference distributions, and the method described by Zhang et al. (2022). For the ISTA style deblending described by Sun et al (2022), the best results across all possible dither combinations was the non-repeating flat dither distribution.

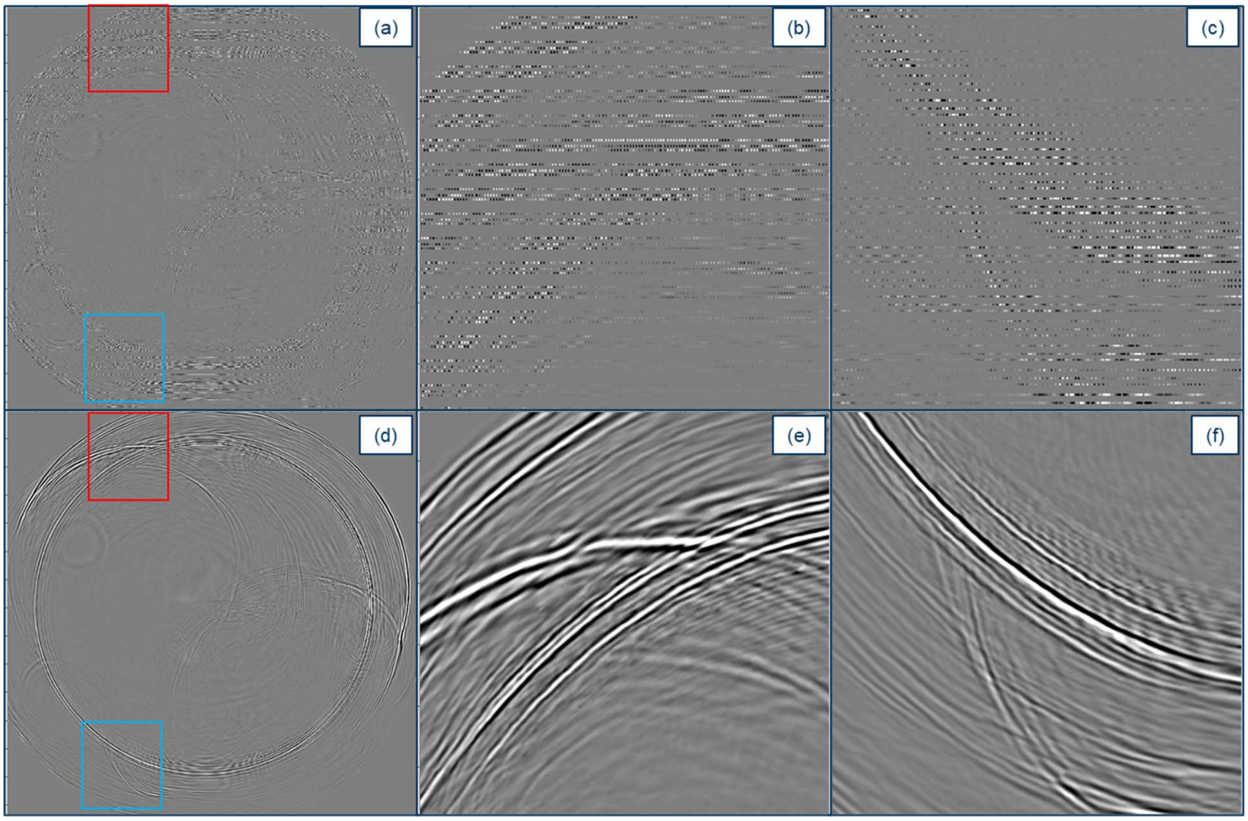

Figure 1 – Time slice at 8 seconds of modelled OBN gather before (a) and after (d) regularization. Red highlighted squares show the effects of variable spread width before (b) and after (e). Blue highlighted squares show the effects of variable surface currents before (b) and after (f).

Previous sparse OBN surveys have been acquired primarily with shooting based on pre-plot source positions with a time dither applied that ensures good deblending results. These surveys have been shot with two sources fired within a small time window, or with a traditional triple source flip-flap-flop configuration. Current regulations require a minimum of 500 ms between two shot events produced from the same vessel. This modelling exercise allowed for testing alternative methods, while still shooting on time to reduce overall time in the field. In order to acquire data with longer times between direct arrival energy, a method was developed to fire all three sources from one vessel within a four second window while ensuring regulated minimum shot time separation and sufficient dither window for deblending. The compressed flip-flap-flop method of shooting minimizes the self interference of the next and previous shots over the quiet times where diving wave energy is recorded or in the deep time section for reflected seismic arrivals.

During the modelling exercise for the blending simulations, it was observed that when firing on time if the two source vessels were using the same primary time interval then the interfering energy from the other vessel tended to occur within a consistent time band on the shots. This significantly complicates the deblending process. Figure 2 shows a modelled source line before blending, and then modelled with compressed flip-flap-flop acquisition with both vessels using the same shot time interval of 19.5 seconds (b and e) and with one vessel at 19.5 second and the other at 19.7 second shot intervals. Each vessel shooting with a different interval significantly improved the deblended results during the exercise. The pattern also reduces the pre-deblending impact on the low frequency diving wave energy needed for the initial bands of FWI.

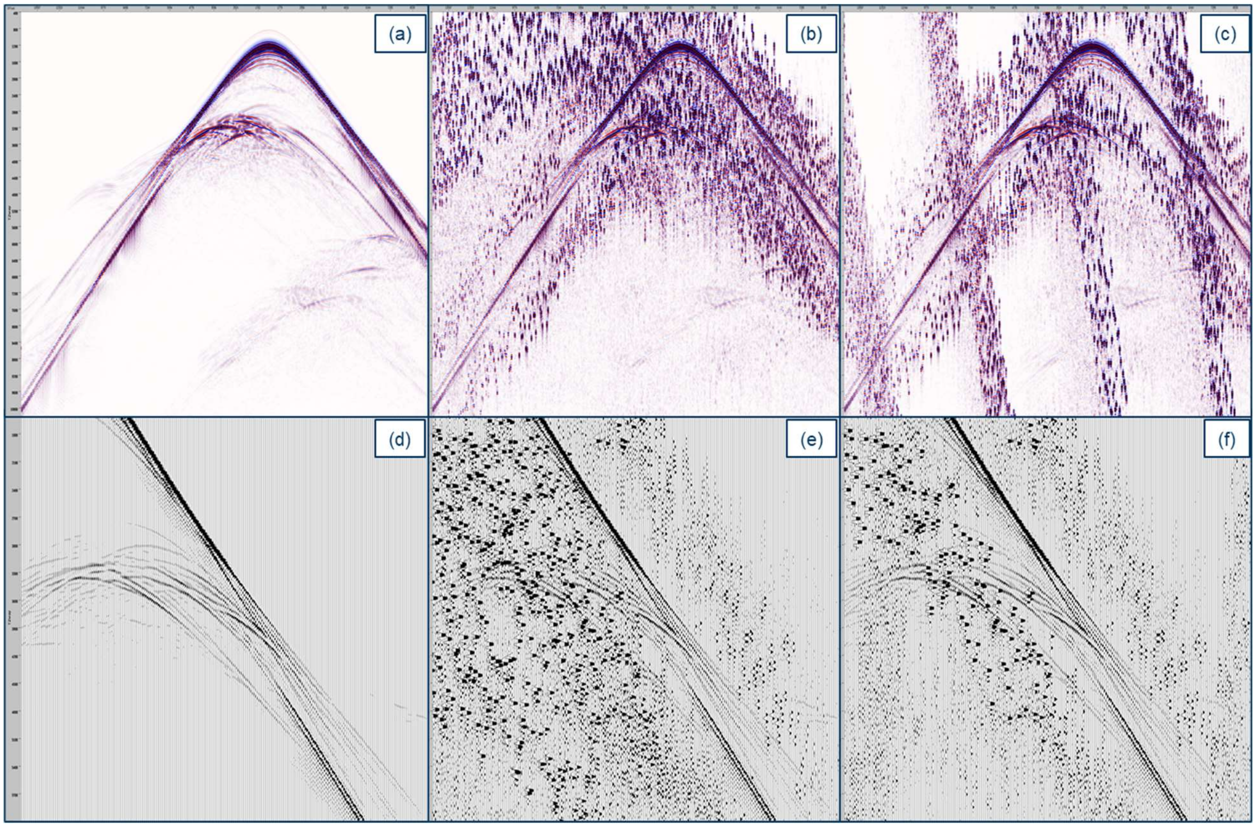

Figure 2 – Realistic model shown for two separate vessel passes. Unblended model (a) and (d), blended gather with both source vessels firing at the same time interval (b) and (e), and blended gather with source vessels firing with different time intervals (c) and (f). Notice the significant coherence of interference in the same time interval shooting, both blended examples are simulated with a +/- 500 ms time dither window.

Upon specifying the desired source dither pattern, source vessel direction, and shot firing method the model data was run through four bands of Dynamic Matching FWI (Mao et al, 2020). Because the modelled data was generated with a known velocity model, a constant input velocity was provided as the starting velocity model. The variation in the inline shot sampling due to current variation and crossline source line irregularity was maintained in the input model to identify any areas of weakness or concern in the output FWI velocity model. Figure 3(a) shows a crossline through the input velocity model, with the final FWI velocity model in Figure 3(c). Figures 3(b) and 3(d) show the RTM image of the same crossline with the true velocity model and the derived FWI velocity model. Even for the most irregular input shot spacing the final velocity model and image are not negatively impacted.

Conclusions

From the modelling study, we were able to determine ideal shooting parameters which would address the effects of the increased vessel speed. Having the two source vessels acquire data with different time intervals was a direct outcome of the modelling study. Setting spread width variance specifications for the acquisition crews was based on the modelling. The study provided a required level of confidence of deblending results using compressed flip-flap-flop and flat dither distributions. The final survey acquisition design was achieved with significant input from the processing and imaging teams for avoiding negative outcomes in the processing of the data that would lead to significant project delays and potential data quality compromises. Additionally, it was proven that seismic processing methods to be implemented could achieve the desired results with a survey acquired with a more efficient source effort than previous sparse OBN surveys.

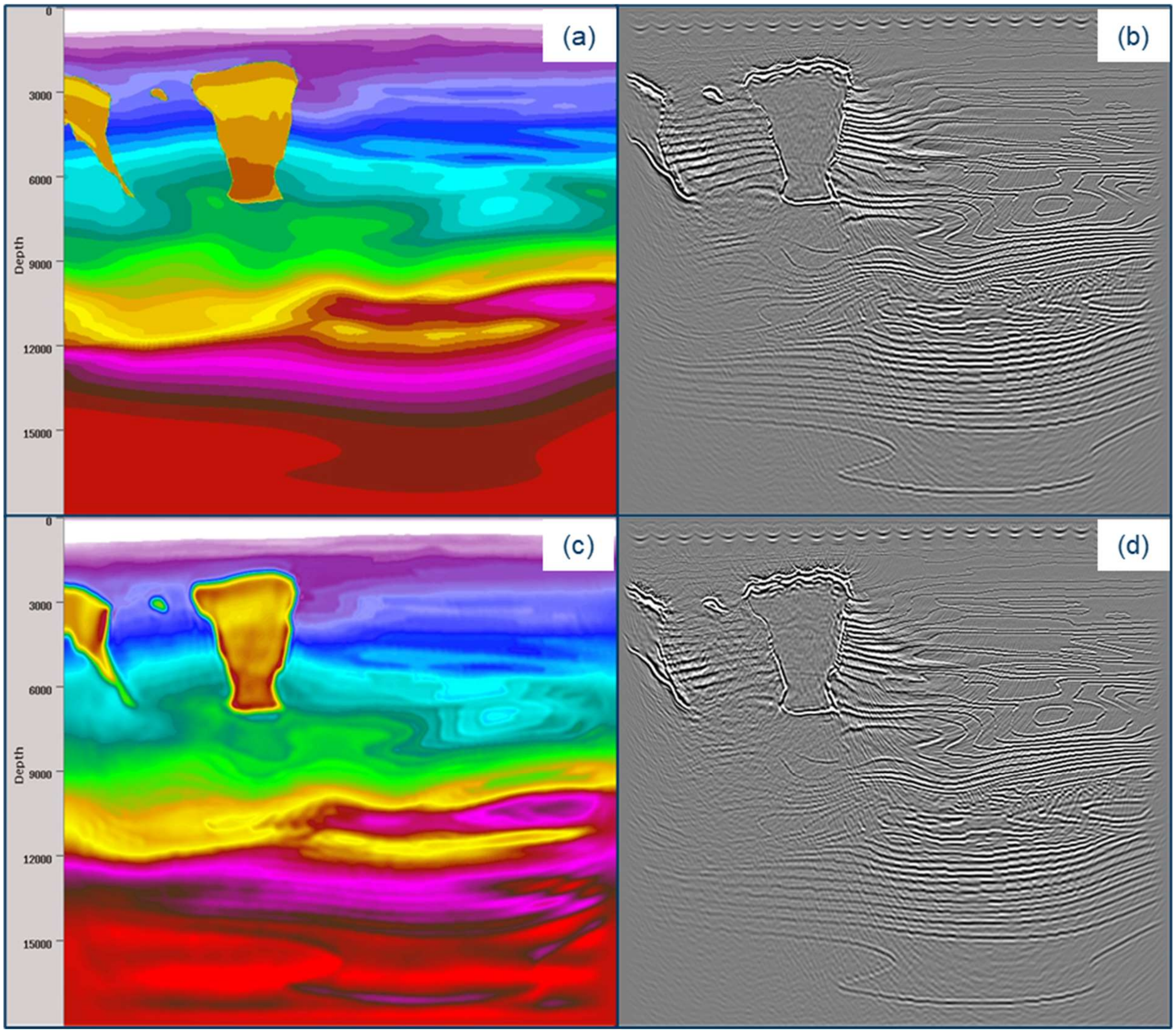

Figure 3 – Crossline velocity model and RTM image through realistic synthetic model. True velocity model (a) and corresponding RTM image (b). FWI derived velocity model and RTM images are shown in (c) and (d). Modelled irregular source line spacing is on the left side of the image, irregular inline shot sampling if on the right.

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