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Separated Wavefield Imaging for Ocean Bottom Surveys - Feasibility Study of Receiver Decimation on a North Sea Dataset

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Summary

We present a method for imaging with separated wavefields from an ocean bottom cable acquisition to deliver images of the subsurface with enhanced illumination and angular diversity. Using this data, we investigate whether it is feasible to decimate the sources or receivers without degrading the structural image from separated wavefield imaging. We conclude by determining if this would be beneficial to reduce acquisition cost and to provide illumination below obstructions like a platform hole.

Introduction

Imaging with separated wavefields (Lu et al., 2015A) uses up- and down-going waves obtained from towed streamer or ocean bottom cable acquisitions to deliver images of the subsurface having enhanced illumination and angular diversity from multiples. When applied in shallow water environments, imaging with separated wavefields is able to lift the illumination restrictions of primaries-only imaging imposed by the critical angle, providing a well-illuminated shallow image with greatly reduced acquisition footprint. In this paper, using data from an ocean bottom survey from the shallow water North Sea, it is investigated whether it is feasible to decimate the sources or receivers without substantially degrading the structural image from separated wavefield imaging. This would be beneficial to reduce acquisition cost and to provide illumination below obstructions like a platform hole.

Method

In ocean bottom surveys, hydrophone and geophone recordings are made at receivers typically placed sparsely at the seabed and using a relatively dense grid of sources at the surface. These recordings can be separated in up- and down-going waves using PZ-summation and subtraction. For the migration, data are organised in common receiver gathers and reciprocity is applied, interchanging source and receiver locations. Migration is then accomplished by extrapolating source and receiver wavefields into the subsurface, and applying an imaging condition. Conventional migration uses the reflections in the up-going wavefield as receiver wavefield and a point source at the water bottom (Figure 1A). Imaging with separated wavefields gives improved illumination over conventional migration of primaries due to usage of multiples of first and higher order (Lu et al., 2015B, Lecerf et al., 2015). Figure 1B shows a sketch of imaging with separated wavefields using the sea surface reflected down-going wavefield as source wavefield and the recorded subsurface reflections in the up-going wavefield as receiver wavefield. The improved extent of subsurface illumination is evident. Figures 1C and 1D illustrate the improvement in angular diversity obtained from imaging with separated wavefields. The multiples provide the angles smaller than the post-critical reflection that are needed to form a good shallow image of the subsurface.

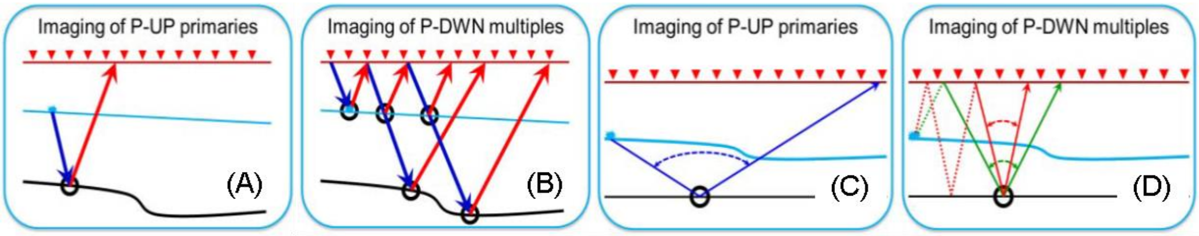

Figure 1 *Sketch of ray-paths used in OBS imaging, after applying reciprocity: (A) imaging of primaries using up-going wavefield (P-UP);(B) imaging of multiples using down-going wavefield (P-DWN). Blue and red arrows denote source and receiver wavefields, respectively. Imaging locations are indicated with circles. (C) Reflection angle from primaries using up-going wavefield; (D) reflection angles from multiples using down-going wavefield.*

Field data example

The field dataset used was an ocean bottom survey acquired in the North Sea. This is a shallow water area with a water bottom depth at about 120 m. Data from a total of 2880 receivers in 12 cables and more than 60,000 shots were available acquired over an area of about 150 sqkm. The ocean bottom cables were deployed 350 m apart, receiver spacing on the cables is 25 m. A dual source flip-flop acquisition was performed with a sailline spacing of 100 m; 50 m between sources and 25 m flip-flop distance along the sailline direction.

To demonstrate the improvement over primaries-only imaging, first a primaries-only wavefield extrapolation migration (WEM) was compared to the reference image from separated wavefield imaging prior to decimation. Subsequently, three decimation tests were performed (Figure 2):

- Omitting every second ocean bottom cable (50% receiver decimation)
- Omitting every second, third and fourth receiver on every cable (75% receiver decimation)
- Platform hole decimation (100% decimation over the obstruction area)

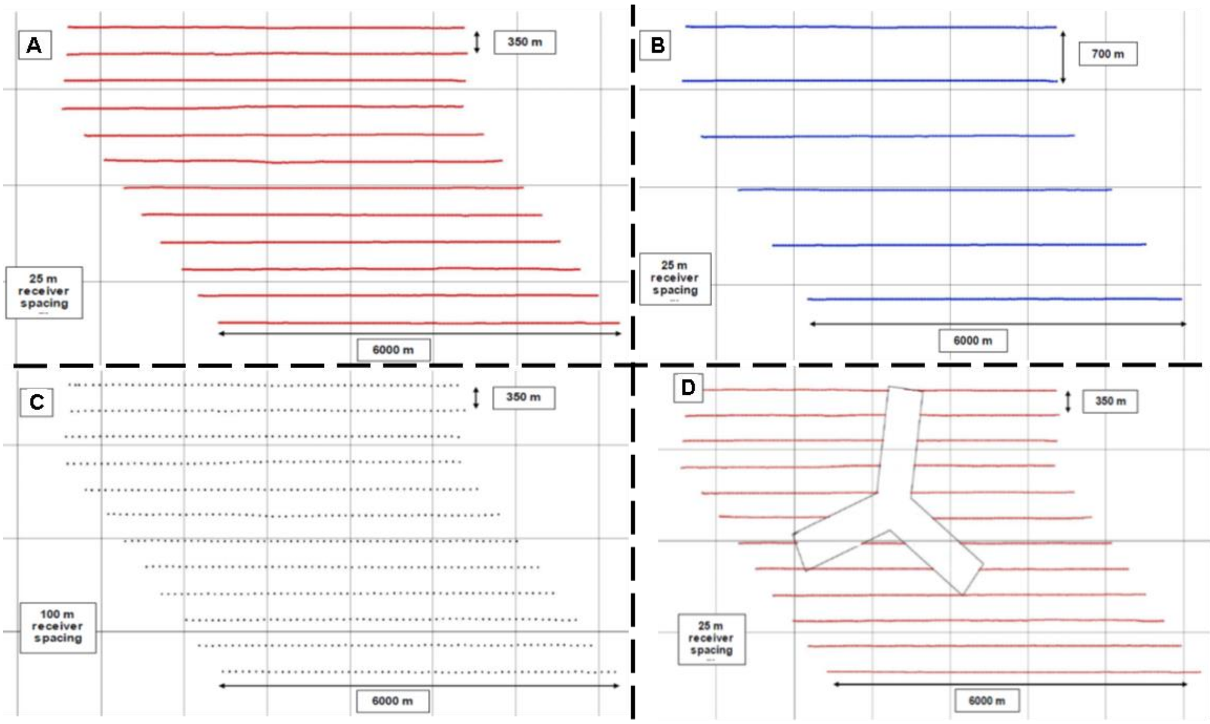

Figure 2 *Decimation tests: top view of ocean bottom cable layout for (A) no decimation, (B) decimation to every 2nd cable, (C) decimation to every 4th receiver on a cable, (D) platform hole decimation.*

Receiver decimation would be beneficial to reduce cost for future ocean bottom surveys in case the enhanced illumination from multiples in the image from separated wavefield imaging proves sufficiently robust. For the platform hole decimation, it was investigated whether the additional illumination from multiples in the image from separated wavefield imaging would allow imaging below the platform. For this test, the receivers were excluded in an area similar in size to a floating storage and offloading vessel with three anchor points that would inhibit receivers from an ocean bottom acquisition to be placed. Sources were excluded in a strip of 2500x300 m around the vessel.

Results

The resulting images of the primaries-only WEM against imaging with separated wavefields are shown in Figure 3. The slice at 160 m depth shows a clear improvement of the illuminated area over the primaries-only migration. The primaries-only migration is not able to illuminate the shallow subsurface much further than the area around the cables. Imaging with separated wavefields benefits from the extended illumination and angular diversity offered by the multiples.

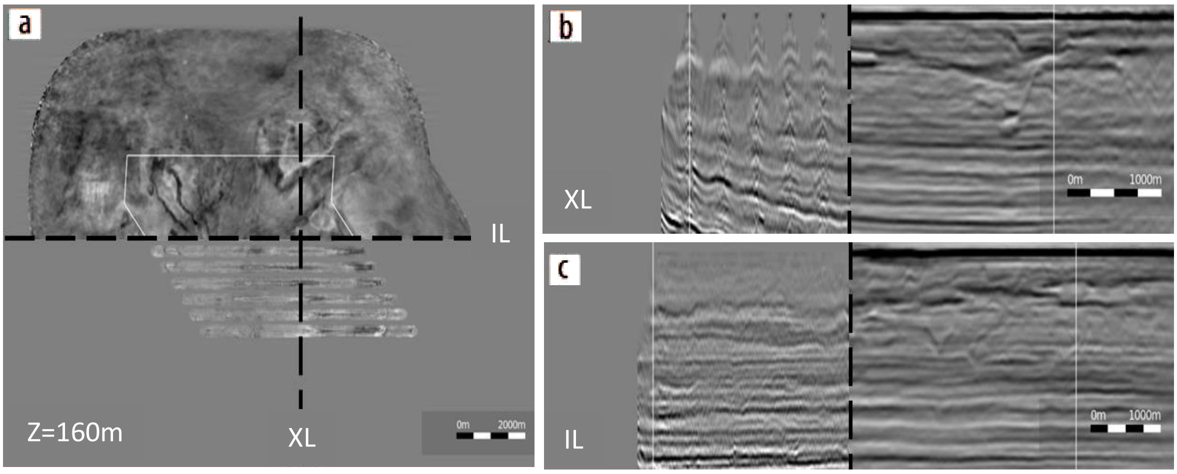

Figure 3 *Images from separated wavefield imaging (3a top; 3b/c right) and primaries-only WEM (3a bottom; 3b/c left). Slice at 160 m depth, and crossline and inline up to 400 m depth. The image from separated wavefields has improved illumination in the shallow, and images between and well beyond the cable patch.*

The resulting images of the decimation tests are shown in Figures 4 and 5. It can be clearly seen that the shallow structural image from separated wavefield imaging (Figures 5b to 5d) hardly changes for all decimations, whereas the WEM images (Figures 4b to 4d) degrades substantially upon decimation. This robustness in imaging with respect to the receiver population would be beneficial for 4D studies as well. Imaging with separated wavefields already lifts a restriction of 4D source repeatability by using a deconvolution imaging condition, providing zero-phase image of reflectivity (Lecerf et al., 2015).

Conclusions

Using the additional illumination and angular diversity from multiples, imaging with separated wavefields is able to image the shallow subsurface where primaries-only imaging suffers due to the illumination restrictions imposed by the critical angle. The additional illumination from imaging with separated wavefields provides an image shown sufficiently robust to substantial decimation of ocean bottom receivers, opening the potential to reduce acquisition cost of ocean bottom surveys. Capability to illuminate below a platform hole was demonstrated as well. Additionally the pre-processing workflow could be simplified as it does not require complex demultiple processes.

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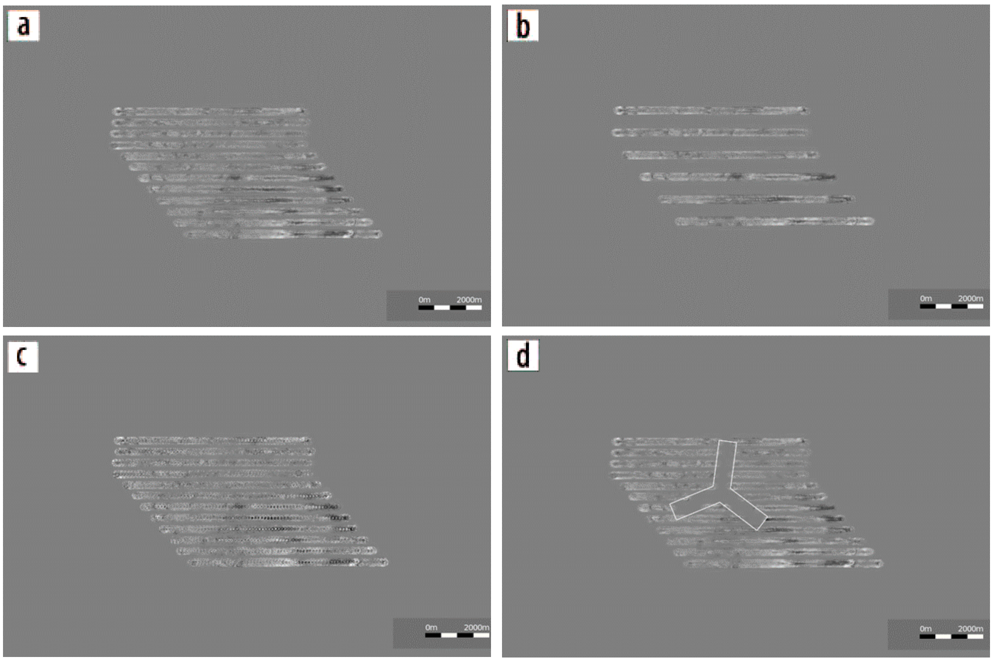

Figure 4 *Decimation tests results: Primaries-only WEM imaging at a depth of 160 m for (a) no decimation, (b) decimation to every 2^{nd} cable, (c) decimation to every 4^{th} receiver on a cable, (d) platform hole decimation, outlined by the white polygon.*

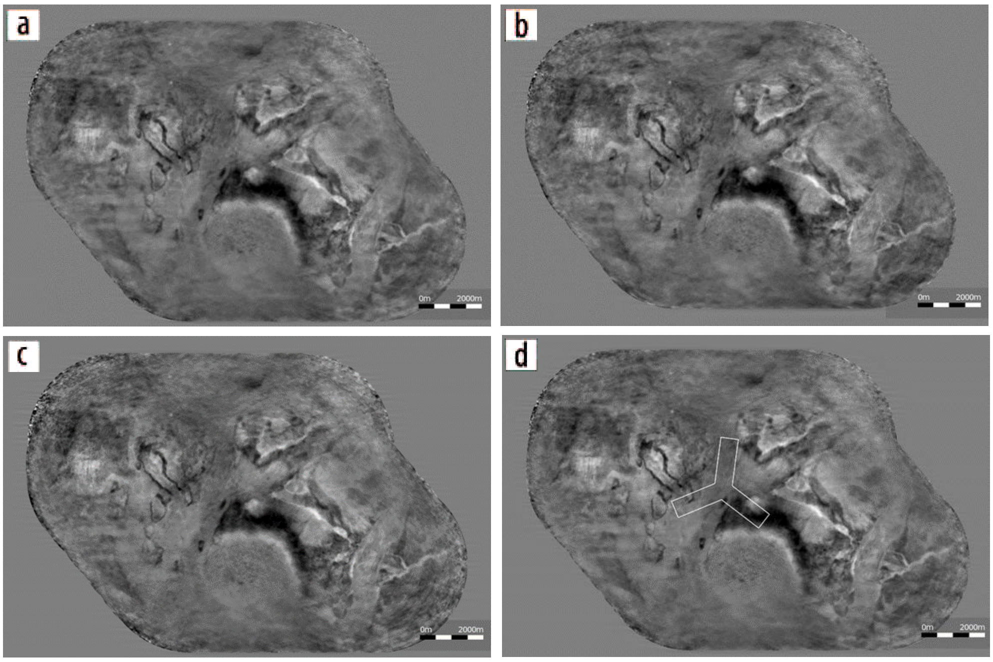

Figure 5 *Decimation tests results: Separated wavefield imaging at a depth of 160 m for (a) no decimation, (b) decimation to every 2^{nd} cable, (c) decimation to every 4^{th} receiver on a cable, (d) platform hole decimation, outlined by the white polygon. Note images (a) to (d) look almost identical; separated wavefield imaging is not adversely affected by decimation in this test.*